May 1954

NUCLEONICS

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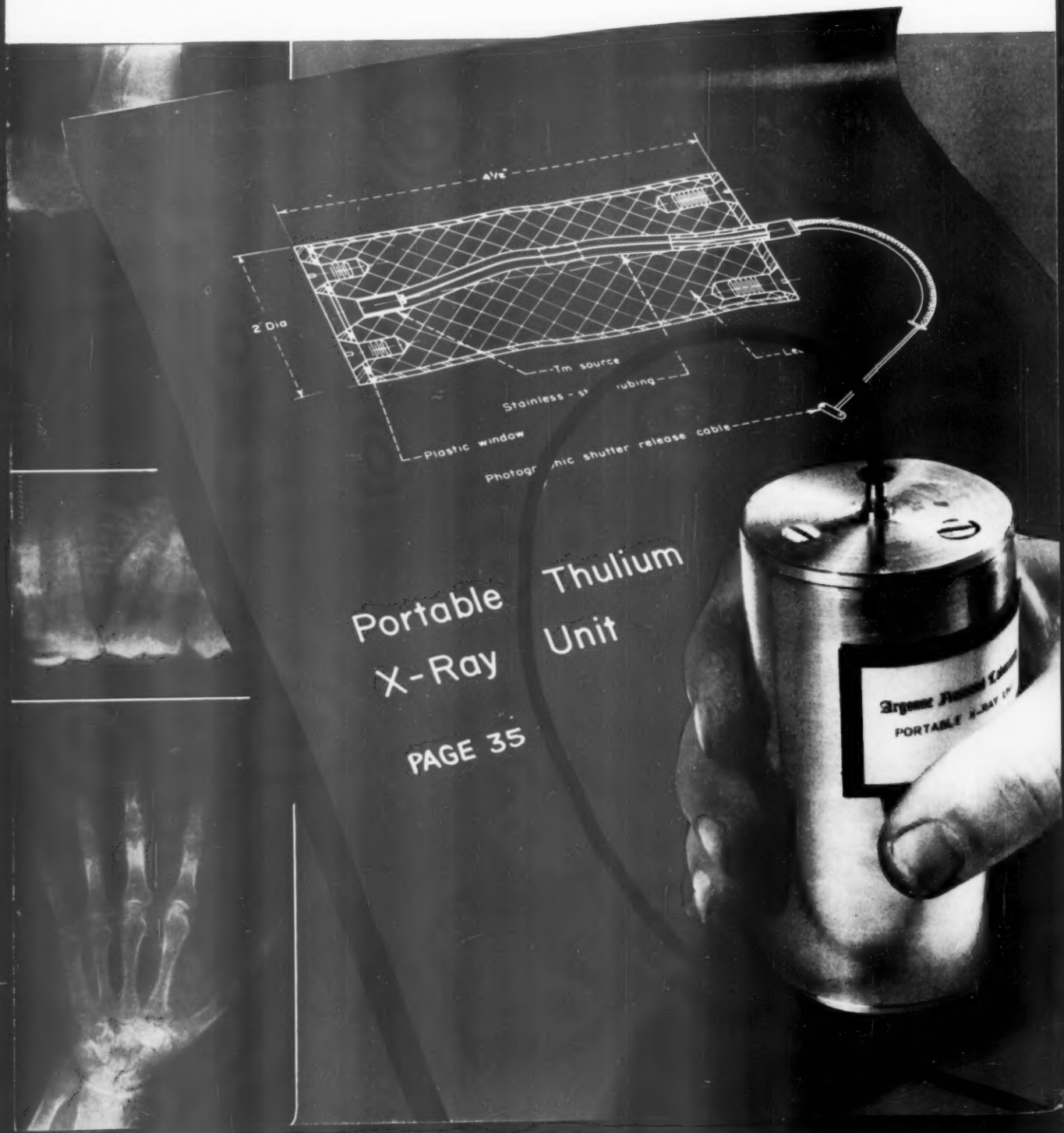

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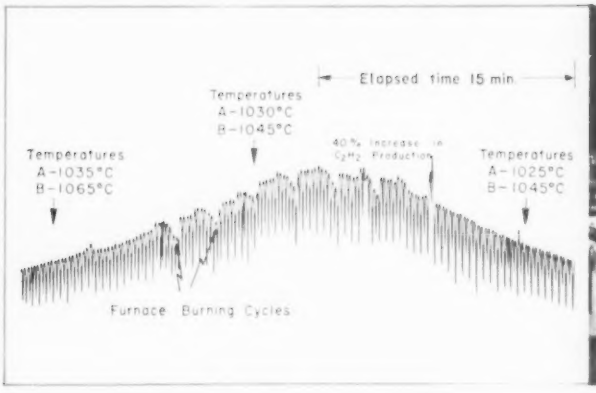

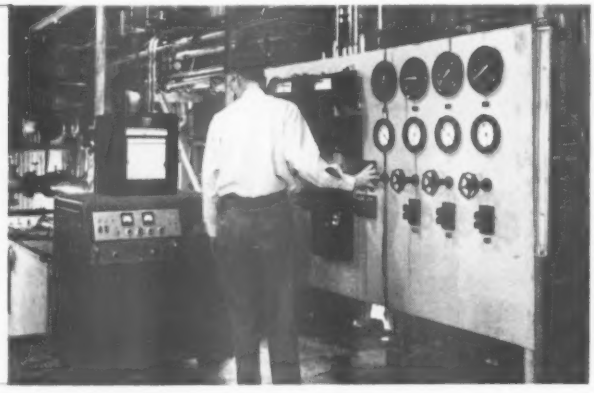

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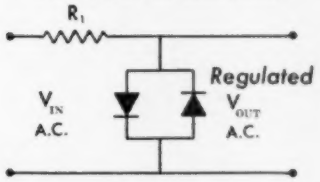

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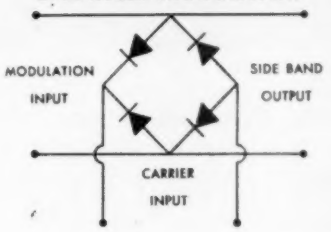

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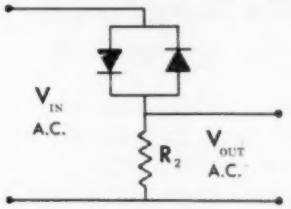

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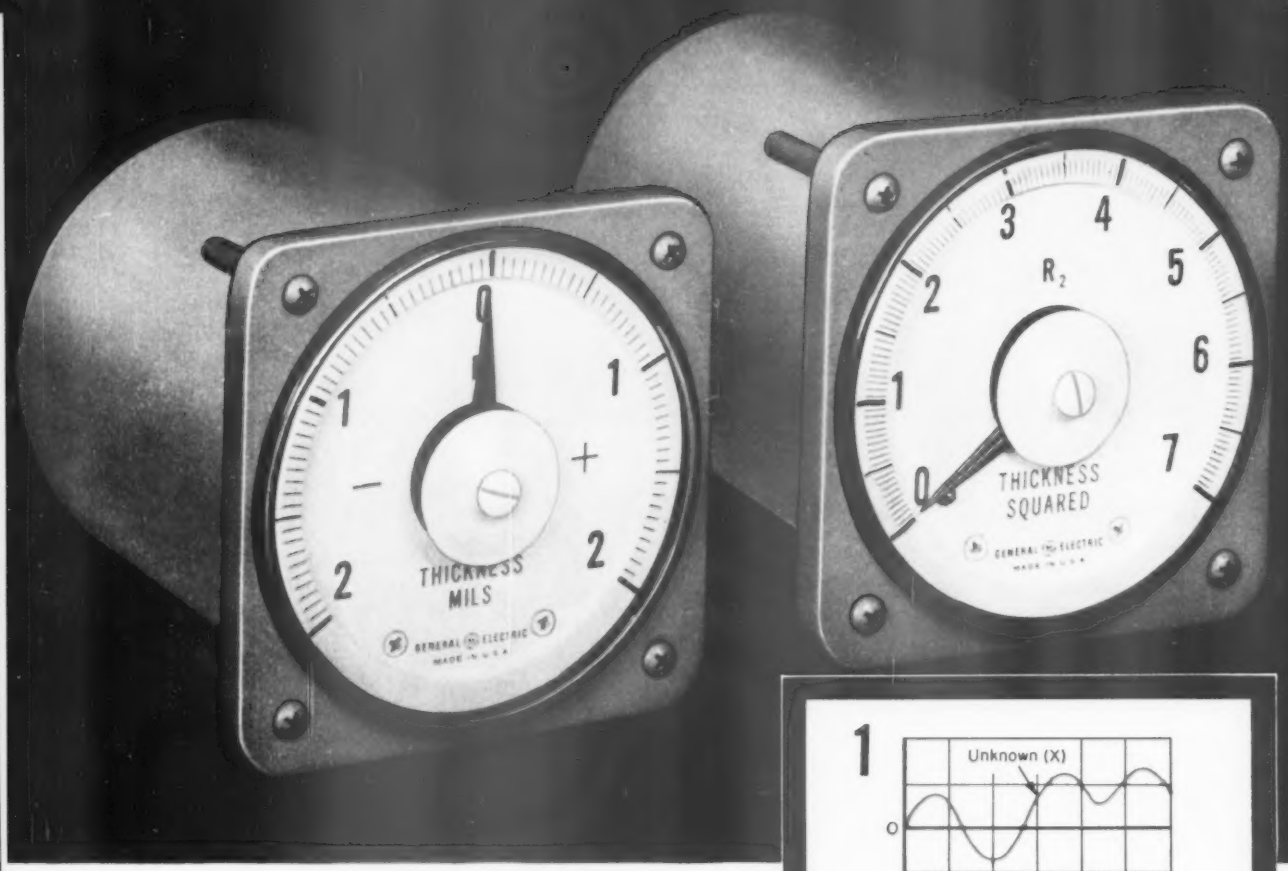

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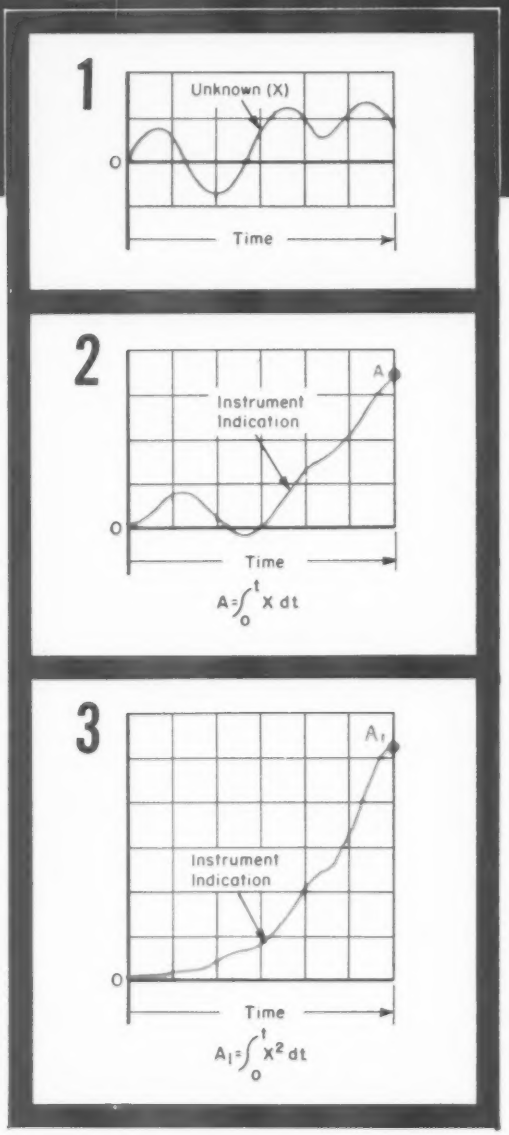


NUCLEONICS

MAY, 1954

Jerome D. Luntz, *Editor*

A Pioneering Move

THE MOST SUBSTANTIAL demonstration of American industry's faith in the future of peacetime atomic energy was made in March. The Duquesne Light Company made a multimillion dollar bet that atomic energy was certain to have a profound effect upon the utility industry. It did this by signing a contract with the AEC to operate this country's first civilian nuclear power plant when it goes into operation in about 1957. It also agreed to pay $5-million toward the reactor.

What is there about this very controversial reactor—the pressurized water reactor (PWR)—that caused a representative of a financially conservative industry to commit itself to such a risk?

Although the Joint Congressional Committee on Atomic Energy has labeled the PWR "least likely to succeed" in the achievement of economically competitive nuclear power, there are those who contend it is a radical reactor and will advance the reactor art. They say it will have the following "unprecedented" features: (1) *slight* enrichment of uranium fuel; (2) burnup of Pu produced in fuel; (3) long core life (high fuel burnup); and (4) production of more than 60,000 electrical kilowatts. It will be the first operating reactor designed to have these features.

BECAUSE THE INTERNATIONAL war of diplomacy has assigned a high time priority to this project, the first version of the PWR will not come close to being economic. However, supporters of the project optimistically stick their necks out and say that a 1964 version of the PWR, having benefited from operating experience and advances in the reactor art, will produce power competitive in the United States.

It may have been a wish such as this that moved Duquesne to make its offer. More likely it was probably that plus something like this: The Duquesne territory, along with the rest of the country, is called upon to increase its capacity by about 4% each year. The company's records show it has several very-high-cost-power plants. Quite possibly one of these plants might be retired shortly and a new plant built to replace it.

A 60,000-kw conventional plant would cost roughly $9–10 million, with the turbogenerator portion, including accessory equipment, costing $4–5 million.

Thus the $5-million Duquesne is contributing toward the reactor part of the nuclear plant plus the cost of a new turbogenerator roughly add up to what it might pay for a similar-sized conventional plant.

The increased cost comes in what it will pay AEC for the power produced plus the increase in cost of operating such a plant. Over a period of 5 years, this additional cost might add up to $5-million. Thus the picture is brighter than would be indicated by AEC's statement that Duquesne will save the Government $30-million through the first five years of plant operation. (AEC undoubtedly included site cost in the figure. Duquesne already owns its site.)

IN ADDITION, Duquesne as owner of the electric generation plant might salvage it at some future date for conventional use. Most important though, throughout its tenure, Duquesne will gain first-hand knowhow on practical problems of the oncoming nuclear age and will be better able to guide itself on such things as knowing when, if at all, it might want to slacken off on maintaining its 25–30 year supply of coal.

There is no question but that Duquesne will be sailing uncharted seas. We salute this pioneering company in its highly significant presentation of material proof of industry's substantial interest in atomic energy.

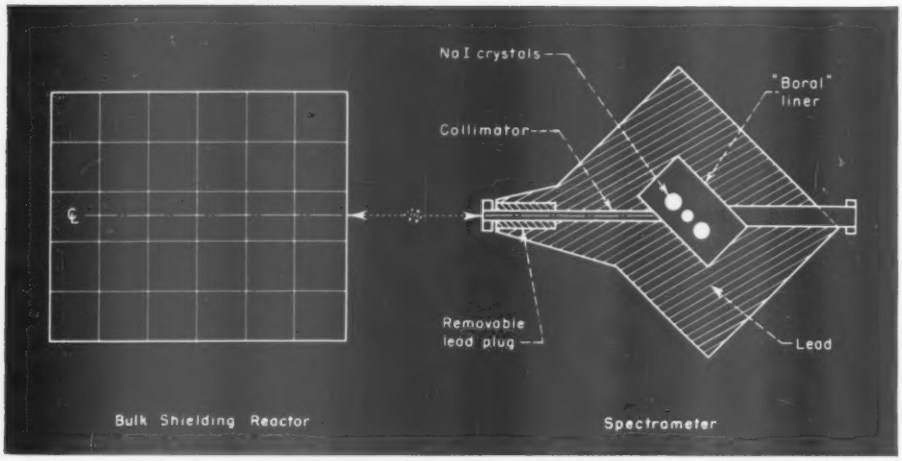


FIG. 1. Reactor-spectrometer geometry for gamma-ray spectral measurements

Gamma-Ray Spectrum of the Bulk Shielding Reactor

Interpretation of shielding data requires a knowledge of reactor gamma-ray spectra. This article shows how scintillation spectrometers have been used to obtain Bulk Shielding Reactor spectra

By FRED MAIENSCHEIN and TEMPLE LOVE
*Oak Ridge National Laboratory**
Oak Ridge, Tennessee

THE BULK SHIELDING REACTOR (BSR) at ORNL is a medium-power reactor of flexible design in which shielding is provided by water above the reactor in a "swimming pool" 40-ft long by 20-ft wide by 20-ft deep (*1*). This article describes gamma-ray spectral measurements of the operating reactor before and after attenuation through various thicknesses of water.

Equipment and Procedure

The BSR consists of an assembly of approximately 30 aluminum-clad enriched-uranium fuel elements. Light water, moved through the elements by convection, acts as the moderator, coolant, and reflector.

The measurements of the reactor gamma-ray spectra were made with two reactor loadings: a "cold" loading and a "hot" loading. The elements in the cold loading had not been operated previously at a reactor power level above 1 watt and, consequently, had not built up any appreciable fission-product activity. This loading was used for measurements made with the spectrometer collimator against the reactor face. The hot-reactor loading consisted of elements that could be (and had been) operated at power levels up to 10^4 watts. It was used for measurements of the spectra of gamma rays transmitted through various thicknesses of water. An additional 3-in. BeO reflector was added for this hot loading.

BSR power level was determined from the fission rate by using the value 193 ± 5 Mev recently measured as the energy released per fission (*2*). This figure was derived from a determination of fission rate through the use of uranium foils and a determination of flux distribution through using gold foils. Knowing these figures, fission rate was calculated.

The scintillation spectrometer used for these measurements utilized either the Compton effect or pair production to give a unique energy response over the energy interval studied (0.2 to 10 Mev).

* Operated for the Atomic Energy Commission by Union Carbide and Carbon Corporation.

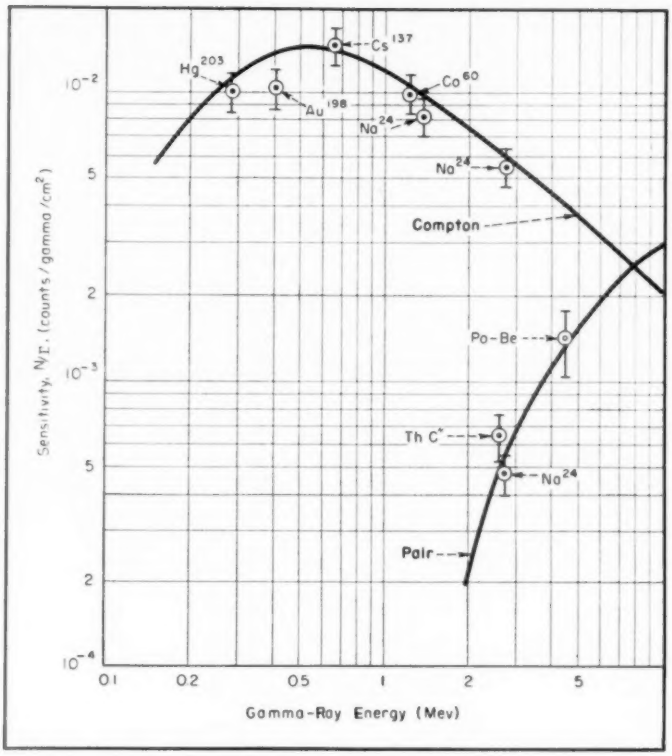


FIG. 2. Sensitivity of multiple-crystal gamma-ray spectrometer

For the method using the Compton effect, two crystals were used in coincidence, one measuring the energy of the Compton-recoil electron, E_e, and the other detecting the scattered gamma-ray (3). Then, since the angle θ between the incident and scattered gamma-rays was known, the incident gamma-ray energy, E_γ, was given by

$$E_\gamma = E_e/2\{1 + [1 + 4/E_e(1 - \cos\theta)]^{1/2}\}$$

The lead collimator that defined the direction of the incident gamma-ray is shown in Fig. 1.

For the method using pair production, three crystals were used in coincidence as shown in Fig. 1. The center crystal measured the energy of the electron-positron pair while the side crystals detected the two annihilation quanta (4). The energy of the incident gamma-ray was

$$E_\gamma = E_e + 2m_0c^2$$

For both methods the pulses from the side crystals were analyzed with single-channel analyzers (5) after suitable amplification. Only those pulses corresponding to an energy of ~0.15 to 0.55 Mev were fed into the gate circuit. Pulse height analysis of the signal from the recoil-electron detecting crystal was carried out with a 20-channel analyzer (6) after this instrument was available and with a single-channel analyzer for earlier runs. This last signal, of course, passed through the gate operated by the pulses from the side crystals.

Energy calibration of the spectrometer utilized the sources: Cs^{137} (0.66 Mev), ThC″ (0.59 and 2.62 Mev), Co^{60} (1.17 and 1.33 Mev), and Po-Be (0.80 and 4.43 Mev). Sensitivity calibrations were made with large sources at sufficient distances from the spectrometer collimator that incident gamma-rays were essentially parallel.

After the source disintegration rates had been determined with an ionization chamber and corrections had been made for the internal conversion coefficients and absorption of the gamma radiation in air, the incident flux at the spectrometer collimator could be determined. The resulting sensitivities, expressed in coincidence counts per unit flux, are shown in Fig. 2.

For the Compton spectrometer, five sources were used. Only Na^{24} was available for the pair spectrometer. The ThC″ point was obtained by using the Compton sensitivity found above. The Po-Be point was determined from the known neutron production rate and an estimate (7) of the fraction of the neutrons leading to the excited state of C^{12}.

The solid lines in Fig. 2 are theoretical curves calculated from the known cross section (8) of sodium iodide and the known solid angles of the spectrometer. Since the errors for this calculation were about ±15%, the good agreement with the experimental results must be somewhat fortuitous.

Measurements of the reactor spectra through water were made with the 2½-ton lead housing for the spectrometer arranged in relation to the BSR as shown in Fig. 1. For all measurements, the lead spectrometer collimator (solid angle, $\Delta\Omega = 1.81 \times 10^{-5}$ steradians) was pointed at the reactor centerline. Water thickness was measured from the edge of the reactor to the end of the collimator.

For examining the reactor spectrum itself, an aluminum tube (5.4 cm dia. by 100 cm long) containing air was placed between the reactor and spectrometer collimator. The water surrounding this air column reduced the neutron flux level incident on the lead walls of the spectrometer to a value that made the neutron-induced background negligibly small. This background was measured by closing the spectrometer collimator with a lead plug as indicated in Fig. 1.

By using two sets of fuel elements, as discussed previously, the background from long-lived fission-product activity was kept small.

Experimental Results

The absolute photon spectra obtained are shown in Fig. 3 with the gamma-ray flux plotted as a function of the gamma-ray energy. Curves are plotted for five different reactor-spectrometer separations. Different symbols are used for data obtained with the Compton and pair spectrometer arrangements.

Discussion

The reactor gamma-ray spectrum is produced primarily by: (1) prompt-fission gamma-rays (2) short-lived fission-product gamma-rays, and (3) neutron-capture gamma-rays. The spectra of

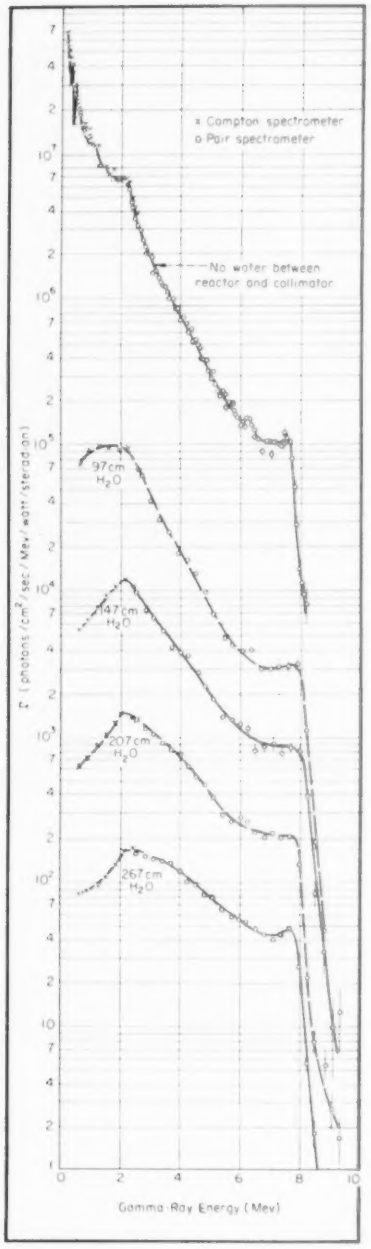


FIG. 3. Gamma-ray spectra of the Bulk Shielding Reactor observed through 0, 97, 147, 207, and 267 cm of water

sources (1) and (2) are largely unknown and the spectra for source (3) have not been investigated for uranium or aluminum below 3 Mev.

With such a complex and largely unknown source of radiation, a detailed explanation of the observed spectra is not possible. However, certain features can be identified.

Table 1 contains a list of peaks present in the data taken with no water between reactor and spectrometer together with the probable sources of some of these gamma-ray lines. Only two of these gamma-rays appear in the spectra observed through water. It should be noted that fewer points were available for the runs through water and thus less prominent peaks might not have been observed. The two prominent peaks observed are due to neutron capture in water (2.2 Mev) and aluminum (7.6 Mev). The water capture gamma-ray becomes increasingly prominent with increasing water thickness because of the rapid absorption of the low-energy portion of the spectrum. The sudden drop of the flux value past 7.6–7.9 Mev possibly is due to the fact that the aluminum capture gamma-ray is the most energetic present in quantities measurable in this experiment.

A "hardening" of the gamma-ray flux with increasing water thickness is apparent, as would be expected since the water cross section decreases with increasing energy throughout the energy region covered.

Counteracting this effect, however, is the "buildup" of the lower energies due to degradation by Compton scattering of the higher energy radiation.

The net result may be expressed in terms of an apparent relaxation length. If the flux at one energy is plotted as a function of reactor-spectrometer separation, a straight line (within 5%) is obtained. Apparent relaxation lengths obtained from such attenuation curves are listed in Table 2, together with relaxation lengths obtained from water cross sections (8).

At the highest energy, the experimentally-measured attenuation length agrees with the value expected from the cross section. At lower energies, the effect of "buildup" is reflected in the larger measured attenuation lengths.

* * *

The authors wish to thank J. L. Meem for many valuable discussions concerning these measurements and to thank Mrs. Grace McC. Estabrook for calculating the flux values. R. H. Ritchie calculated the theoretical sensitivity of the spectrometer and Mrs. Elizabeth B. Johnson made the reactor power measurements.

BIBLIOGRAPHY

1. William M. Breazeale, NUCLEONICS **10,** No. 11, 56 (1952)
2. J. L. Meem, NUCLEONICS **12,** No. 5, 62 (1954)
3. R. Hofstadter, J. A. McIntyre, *Phys. Rev.* **78,** 619 (1950)
4. Sven A. E. Johansson, *Nature* **166,** 794 (1950); J. K. Bair, F. C. Maienschein, *Rev. Sci. Instr.* **22,** 343 (1951)
5. J. E. Francis, Jr., P. R. Bell, J. C. Gundlach, *Rev. Sci. Instr.* **22,** 133 (1951)
6. George Kelly, NUCLEONICS **10,** No. 4, 34 (1952)
7. J. Terrell, *Phys. Rev.* **80,** 1076 (1950)
8. Gladys White, NBS-1003, 76 (National Bureau of Standards, U. S. Department of Commerce, Washington, D. C., 1952)
9. F. Ajzenberg, T. Lauritsen, *Revs. Modern Phys.* **24,** 321 (1952)
10. R. E. Bell, L. G. Elliott, *Phys. Rev.* **79,** 282 (1950)
11. B. B. Kinsey, G. A. Bartholomew, W. H. Walker, *Phys. Rev.* **83,** 519 (1951)

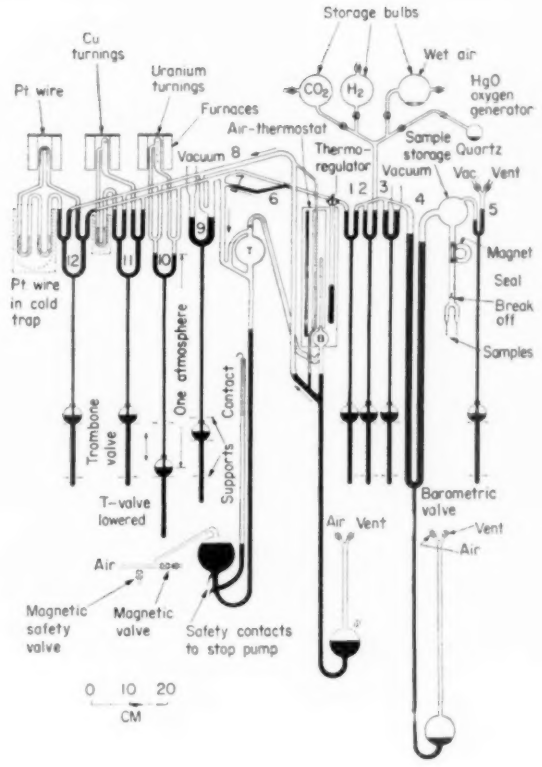
TABLE 1—BSR Gamma-Ray Lines

Energy (Mev)	*Possible reaction producing gamma-ray*
0.40	
0.49	$B^{10}(n,\alpha)^*$ (9) + annihilation radiation
1.2	
2.2	$H^1(n,\gamma)$ (10)
6.2	$Al(n,\gamma)$? (11)
7.6	$Al(n,\gamma)$ (11)

* From boron in "boral" spectrometer liner

TABLE 2—Apparent Relaxation Lengths of BSR Gamma Rays

Gamma-ray energy (Mev)	*Reactor-spectrometer separations for which an exponential absorption is observed (cm)*	*Relaxation length (cm)*	
		From these tests	*From cross section (8)*
1	147–267	28	14
2	147–267	29	20
4	97–267	34	30
6	97–267	40	37
7.6	97–267	40	41



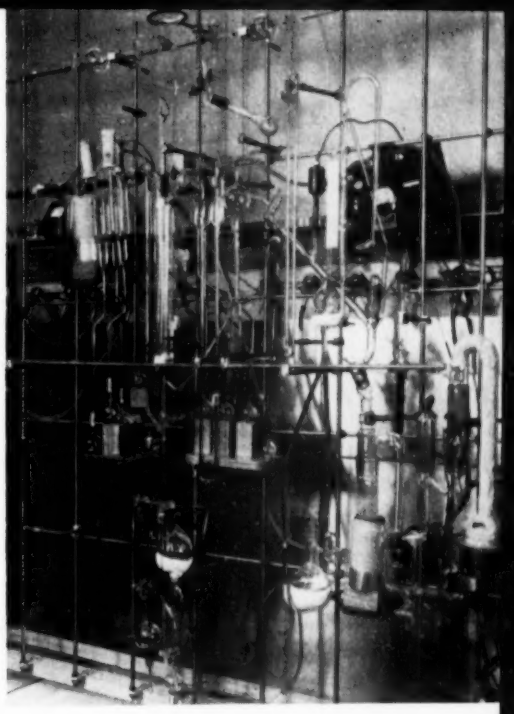


FIG. 1. Gas microanalysis system is drawn to scale (left) and shown in use at one stage of development (above)

Water-Boiler Data

Composition, Decontamination of Radioactive Gas Mixtures

A system of volumetric microanalysis has been developed to determine the chemical composition of reactor off-gases with radioactive components. Three methods for reducing the activity of such gases are also discussed

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METHODS HAVE BEEN DEVELOPED for determining the composition and reducing the volume of contaminated gases from the Los Alamos homogeneous nuclear reactor (*1*). A catalyst system for recombination of a portion of these off-gases from the "Water Boiler" has been described previously (*2*); this article describes techniques and results of off-gas analysis, and considers methods for off-gas disposal.

In 1952 the practice was to operate the Water Boiler about 6 hr each day at a maximum power of 36 kw. Approximately 100 ml/min of air were forced into the system to keep the radioactive gas flushed from the pressure gage lines (*2*). The uranyl nitrate solution in natural water was radiolytically decomposed and the resulting gases with the fission products were mixed above the liquid in the sphere. These gases were circulated through a platinum-on-alumina catalyst to combine the hydrogen and oxygen. The water formed was condensed and added to the solution in the reactor. Nitrogen and more oxygen than was needed to burn the hydrogen were also released from the solution.

A method was needed to determine the composition of the off-gas from the reactor. This gas is highly radioactive

FIG. 2. Sampling system with part of the shielding removed

FIG. 3. Sampling system with entire shield in place

and must be manipulated in small quantities to reduce the radiation hazard. Most of the radioactivity of the gas vented from the recombiner system resulted from the iodine and bromine decay chains that yield xenon and krypton and, finally, solids. Particularly bad from the health standpoint would be the escape of iodine, which will accumulate in the body. Because of this, the limit of 8-day I^{131} permissible in breathable air has been set at only 3×10^{-9} mc liter. The maximum limit for the other gases is 2×10^{-6} mc l. However, there has been evidence (*3, 4*) indicating that very little iodine was removed from the uranyl nitrate solution of the reactor; therefore, the activity of the gas stream was caused mostly by xenon and krypton.

When various volumetric and gravimetric methods were considered, a microvolumetric system was adopted. Determinations are made by removing one component of a sample of the gas mixture at a time, either by absorption by a specific reagent or by freezing at a controlled temperature. Between each component removal, the gas is collected in a constant-volume thermostated tube and the pressure observed.

Equipment

A glass system was built, as shown to scale in Fig. 1, so that a sample of gas could be introduced from a glass bulb and its composition determined without the gas being in contact with any material other than glass, mercury, and the specific reagents. Figure 1 also shows the system in use at one stage of development.

Gas mixtures for analysis are received in glass tubes, one of which is shown sealed to the sample storage bulb in Fig. 1. These contain about 4 ml of gas at atmospheric pressure that is trapped by sealing off the capillary tubes. When the sample tube has been sealed to the storage bulb, an iron weight enclosed in a heavy-wall glass tube is dropped to crush the break-off tube and thus release the gas to the evacuated storage bulb. Aliquots of this sample or known gases from other storage bulbs can be admitted to the analysis assembly by means of the trombone valves 1, 2, and 4. In these valves the bottom of the Pyrex U-tube is connected to a small-diameter tube that extends well below the surface of a mercury reservoir. This is located sufficiently far below the U-tube that the atmospheric pressure can not push the mercury high enough to close the tube. The reservoir is so supported that it can be raised to a higher position by the insertion of a block under it, which causes the mercury to rise and close the tube.

A mercury diffusion pump is used to produce a high vacuum in the equipment and is connected to the system by means of valves 3 and 9. Valve 9 is double-acting and can be used to interconnect the two reagent manifolds, 7 and 8, and to evacuate the system.

The gas sample can be circulated over the reagents or compressed into the 50-ml measuring bulb, *B*, by means of the 200-ml Toepler pump, *T*. This pump is automatically operated by compressed air and is controlled by relays. It stops after 10 cycles, if the gas is being collected for measurement.

The quantity of gas is found by raising the level of the mercury above *B* so that the gas sample is trapped in the calibrated dead-end tube in the air thermostat. At a controlled temperature and known volume, the pressure is measured by observing the height of the mercury column in the adjacent evacuated tube of the same diameter, 3.2 mm. It is not practical to use capillary tubing at this point because of the tendency of the mercury to cling to the wall and give an erroneous indication of the gas pressure.

A small quantity of mercury follows the gas from the pump to *B* during each cycle. This is returned to the pump by raising the mercury level above *B* until the mercury flows through the trap, 6. Whereas the equipment in Fig. 1 is drawn to scale, as constructed, the pump, *T*, is located behind the thermostat so that the manifolds 6, 7, and 8 are shorter than shown. In this way these tubes can have a smaller

TABLE 1—Radioactive Gases from Fission with Half-Lives Greater Than One Minute

Br^{82}	35 h	Kr^{85}	2.8 h	I^{136}	1.4 m
Br^{83}	2.4 h	Kr^{87}	2.6 m	Xe^{131}	12 d
Br^{84}	33 m	I^{129}	10^8 y	Xe^{133}	5.27 d
Br^{85}	3 m	I^{131}	8.0 d	Xe^{135}	13 m
Kr^{83}	1.9 h	I^{132}	2.4 h	Xe^{135}	9.2 h
Kr^{85}	4.4 h	I^{133}	22 h	Xe^{137}	3.9 m
Kr^{85}	9.4 y	I^{134}	54 m	Xe^{138}	17 m
Kr^{87}	78 m	I^{135}	6.7 h		

volume without a decrease in diameter and pumping speed.

Analysis

The gas mixture resulting from the radiolytic decomposition of aqueous uranyl nitrate solution is analyzed in the following order:

1. Carbon dioxide plus moisture by freezing with liquid nitrogen.
2. Moisture separated from carbon dioxide by fractional sublimation.
3. Hydrogen by combustion with the excess oxygen usually present.
4. Oxygen by oxidation of hot Cu.
5. Nitrogen by reaction with hot uranium turnings.
6. Inert gases by difference.

Reagents

Water and carbon dioxide. Magnesium perchlorate can be used to remove water at a few centimeters pressure, and it can be regenerated by heating at 250° C in a vacuum. However, in a high vacuum this reagent was found to lose moisture even at room temperature. The other chemical desiccants considered would also react with other components of the mixture. Therefore, after measurement, the gas to be analyzed is passed through the traps at 12, one of which is cooled with liquid nitrogen. After continuous circulation for 30 min, the remaining gas is collected and measured. This treatment removes moisture and carbon dioxide. Hydrogen peroxide and the oxides of nitrogen, if present, are also removed, but these gases are not detected in the mixtures studied.

In tests made with this trap cooled to −50, −85, −95, and −102° C, the moisture was never completely removed from the mixture. Therefore, the mixture is first cooled as above with liquid nitrogen; then, by the use of another cold trap in series, the gas collected in the first trap is separated by fractional sublimation to the second trap, which is cooled with solid carbon disulfide at −102° C. Under these conditions moisture is removed, and the carbon dioxide can be collected and measured with the other gases stored in the measuring bulb.

Hydrogen. With all of the gases removed that have low vapor pressure, the same tube, 12, is used at −196° C for combustion and freezing. All of either hydrogen or oxygen is removed by combustion on a hot platinum wire and subsequent freezing in the liquid nitrogen trap. The platinum wire in the quartz tube enclosed in the furnace is heated to a dull red heat, 700° C, and the gas mixture circulated for 20 min. While the analysis is being conducted, an excess of oxygen is present so that all the hydrogen is removed at that time. When a sample does not contain sufficient oxygen, a measured quantity is added from the generator by heating the mercuric oxide. Hot copper oxide is not used to burn the hydrogen because it was found to be very difficult to degas (*5*).

Oxygen. The excess oxygen not combined with the hydrogen above combines with copper heated to 350° C. Valve 12 is closed and the gas passed over fine copper turnings that are heated in a quartz tube, 11. This copper is reduced occasionally between analyses by the circulation of hydrogen and by heating to 350° C. The trap should be cooled with liquid nitrogen to remove the water as it is formed.

Since the oxidation of copper is slow, it is necessary to circulate the gas for 1 hr to be certain that all the oxygen is removed. When no reduction in quantity of gas is observed, sufficient oxygen may not have been present when the hydrogen was burned in the previous step. In such a case another analysis is made with more pure oxygen added from the generator.

Nitrogen. Both hot calcium and magnesium will react with nitrogen, but the vapor of either was found to react rapidly with the quartz container, causing it to shatter. In the nitrogen determination, the systems used for the other steps are isolated, and the gas is passed over uranium turnings at 750° C for 30 min (*6*). The metal surface is prepared by removing the oxide with dilute nitric acid in an inert atmosphere before placing the metal in the quartz tube in the assembly.

The uranium samples used here continued to give off a trace of hydrogen, even though they were well cleaned of oil and dried before heating. This small quantity of hydrogen was removed from the remaining gas by

TABLE 2—Analysis Checks

Test	H_2O	CO_2	H_2	O_2	N_2	*Inert*
46 present	1.9%	44.4%	9.0%	9.3%	37.7%	0.4%
found	0.5	44.6	9.1	8.8	34.7	1.7
47 found	0.9	0.5	1.4	21.4	73.8	1.9
48 check	1.6	0.1	1.6	21.3	74.2	1.4
49 found	0.2	0.2	0.0	26.4	71.5	2.0
51 check	0.1	0.5	0.0	26.7	71.9	0.8
	$H_2O + CO_2$					
63 found	0.6		6.1	26.5	65.9	1.4
66 check	0.5		6.1	27.1	65.2	1.8
67 found	0.4		0.3	26.9	75.1	1.1
68 check	0.7		0.2	26.8	—	—
54 present	0.3		6.67	19.5	72.9	0.9
55 found (heating tubes)	0.4		6.6	18.9	72.9	1.7
56 found (heating tubes)	0.5		6.4	19.3	—	—
59 found (gamma radiated)	0.1		6.8	18.9	72.4	1.8

TABLE 3—Percentage Composition of Water Boiler Gas (dry basis)

Test	$H_2O + CO_2$	H_2	O_2	N_2	*Inert*
70 Before catalyst	0.8%	6.7%	36.3%	55.7%	1.3%
71 Before catalyst	0.2	6.6	36.6	—	—
72 After catalyst	1.0	0.4	38.5	59.9	1.3
73 After catalyst	0.2	0.7	38.4	59.9	1.2
Air for reference	—	0.00	20.95	78.09	0.93

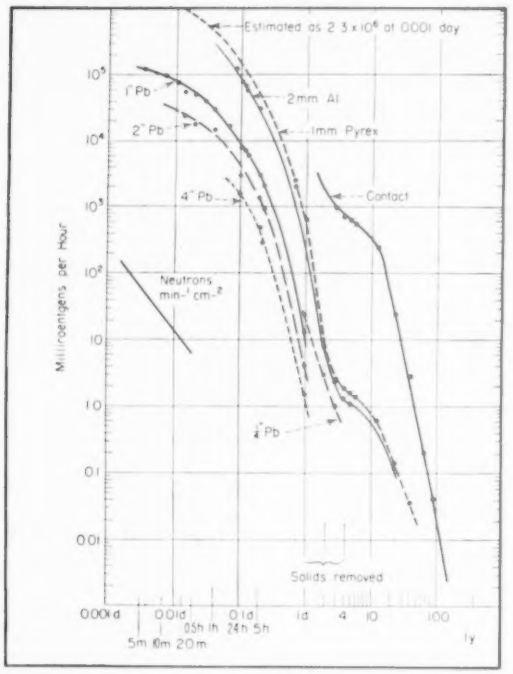

FIG. 4. Decay of radioactive water-boiler gas. One liter sample removed directly from reactor after several hours of 30-kw operation

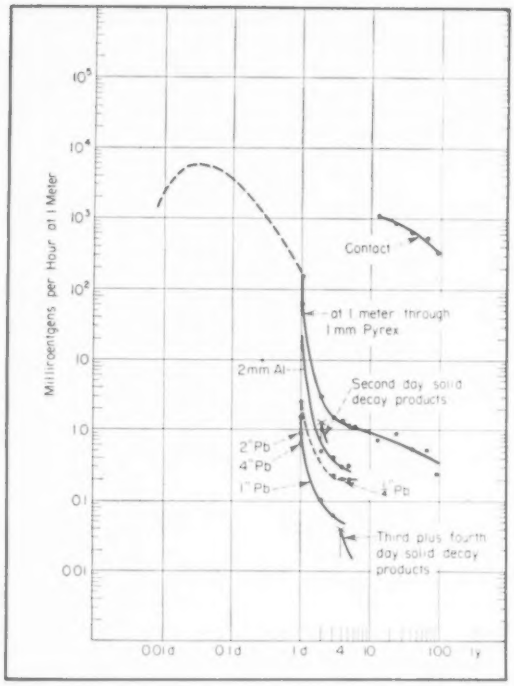

FIG. 5. Observed activity of solid decay products removed from 1 liter of water-boiler gas at end of first 24 hr

passing it over the hot copper sample just used to remove oxygen. The copper oxide film reacted with the hydrogen to form water, which was removed by the cold trap.

Inert gases. Only inert gases can escape reaction with the hot uranium or the earlier oxidation and freezing. Therefore, the remaining inert gas is measured and a qualitative identification made by observing the color when the gas is ionized by an electric discharge.

Shielding

Most radioactive gases have a short half-life. Radiation is reduced by placing a shield over the sample storage bulb and using a small sample.

The samples, which were taken by the method described later, were allowed to decay for 2 days before analysis. At this time the activity was only 20 mr/ml at contact for the total sample. The valves were operated from a short distance, and the pressure measurements were made with a cathetometer at a distance of about 2 meters. During these analyses the operator received very little radiation.

A few measurements were made of the rate of decay of the gas removed from the homogeneous reactor while it was operating at 25 kw. When the gas was first collected, its radioactivity exceeded 1 c/ml at standard pressure and temperature, and neutrons were detected outside the shield. The radioactive gases from fission result mostly from the xenon and krypton decay series and are shown in Table 1.

Sampling

The gas sample collection system used at the homogeneous nuclear reactor was built in duplicate so that samples could be taken from different places simultaneously. The entire sample system was evacuated by charcoal cooled with liquid nitrogen. The charcoal tubes were turned off to vacuum-test the entire system.

Each system was constructed so that the radioactive gas could be admitted from the original container through the sample tube into a 1-liter container. When the gage showed the system to be at atmospheric pressure, the valve was closed and the two capillaries on each sample tube were sealed and melted off. The liter of radioactive gas was left in place until it had decayed enough to be removed by the charcoal. Four inches of lead surrounding the stainless-steel sample lines and 8 inches of lead around the 1-liter brass storage bulbs were required to shield this gas when it was collected.

Figure 2 shows the sampling system with part of the shielding removed and one unused sample tube on top. Figure 3 shows the entire shield in place.

Several samples of gas of known composition were collected in these tubes to test the method of sealing. By determinination in the micro equipment, the composition of the gas was found to be unchanged by heating the capillaries. Enough gamma radiation from a cobalt source to darken the glass tubes to the same extent as they were darkened by water-boiler samples left the gas unchanged.

Results

In Table 2 are tabulated the results of some analyses, 46–51 and 63–68, made to check the equipment, and other analyses, 54–59, made to observe the effect on the mixture of heating the capillary tubes and the effect of gamma radiation.

Some air was admitted continuously to the gas system of the homogeneous reactor. To this air were added the radiolytic decomposition products of

the aqueous uranyl nitrate solution. A great quantity of hydrogen was formed, and it was converted to water by circulating the mixture over a platinum catalyst. Samples of gas taken before and after passage over the catalyst were analyzed. A set of these data has been listed with the known composition of air in Table 3. The $H_2O + CO_2$ column contains all material with low vapor pressure at −196° C.

If decomposition of the nitric acid by radiation yields only hydrogen, nitrogen, and oxygen, then the catalyst should combine the hydrogen with some of the oxygen to form water. The remaining gas should contain oxygen and nitrogen in the ratio of 2.5 to 1. When gas of this composition is added to the flushing air, the composition should be altered in the direction of that observed.

A conversion of the percentage composition of each gas before contact with the catalyst to a hydrogen-free basis increases the nitrogen and oxygen, but not to the values found after contact with the catalyst. No explanation for this discrepancy has been found.

To eliminate any oxygen and nitrogen in the system at the start, on two occasions the gas in the recombiner system of the water boiler was replaced by argon. Normal flushing air also was replaced by a small flow of argon. In Table 4 are tabulated the analyses of the gas before and after the reactor was operated in each experiment.

The ratio of oxygen to nitrogen formed was found to be only 2.2, compared to 2.5 expected.

The probable cause of the lowered ratio was a small air leak. Also, the quantity of nitrogen that had to be added to the gas to give it the final observed composition was calculated to be 45 ml/min, and only 24.3 ml/min could have been formed from the nitric acid known to be consumed.

Disposal Methods

Three methods for further decontamination of the gas have been considered. First was the method in use of comparatively slight delay and great dilution by air in a stack. The second method involved use of large delay tanks in which the gas would have time for considerable decay before being vented. Last, it was found that in passing over activated charcoal, the radioactive components were adsorbed and removed from the gas stream.

In considering the first method, observations were made of the periods of reactor operation and the activity fluctuations at both ends of the 1,100-ft long vent pipe that extended from the reactor to the stack. There was little mixing as the gas flowed through the 2-in. (inside diameter) pipe. This was equivalent to a 24-ft³ delay tank, or a delay of 2.3 days. It is shown in the following paragraphs that the gas activity should have been reduced to about 9 mr/liter at 1 meter in this time. Several measurements were made of this activity just before the gas entered the stack. The observed activity varied from 0.4 mr to 20 mr. In the stack the active gas was diluted 100,000 times with air and vented 150 ft above the ground. The total average activity at the top of the stack is probably $\sim 1 \times 10^{-4}$ mc/l.

A possible method of gas decontamination would be delay tanks. The decay rate of the gas mixture was followed. A 1-liter sample was removed after the reactor had operated 4 hr at 35 kw. The activity of the gas was measured through 1 meter of air and 1 mm of Pyrex. Effects of various shields were also observed. This information is shown graphically in Fig. 4. At 1, 2, and 4 days the gas was transferred to clean, glass-wool-filled bulbs so that the activity of the secondary solid decay products could be followed. The activity of these bulbs is shown in Fig. 5. It was observed that the half-life of the mixture was about equal to one-fourth of the time that the gas had been out of the reactor.

At present, the apparent advantage of the decay tanks is that they require almost no maintenance. However, they have the disadvantage of being very large if a long decay period is desired, and eventually the gases will have to be released to the atmosphere. Storage space of 180 liters would be required for each day of delay when 200 ml/min of gas are discharged.

In another series of experiments it was found that activated charcoal will remove the radioisotopes from the gas. A 1,700-gm sample decontaminated the gas stream for 6 hr. Its useful life was found to be a function of the total gas flow instead of the power of the reactor. Therefore, it must have been deactivated by the moisture carried by the gas. The gas flow was about 100 ml/min (flushing air) at zero power and about 200 ml/min when the reactor was operated at 36 kw.

A charcoal trap system would probably be smaller than a decay tank system, but would require regenerating once each month. It can be estimated now that a trap containing less than 100 kg of charcoal would be adequate to decontaminate the gas stream for a month. Another trap could be used for a second month while the active isotopes caught in the first could decay enough to be concentrated in a small tube and then buried.

* * *

The author wishes to express his appreciation to L. D. P. King, R. P. Hammond and W. R. Wykoff for their technical assistance, F. Fitzgibbon and M. Redman of CMR-10 who assisted in the experimental work, and L. E. LaMar for aid in compiling reference material.

BIBLIOGRAPHY

1. L. D. P. King. The Los Alamos homogeneous reactor, Supo model. LADC-1,081 (1951)
2. L. D. P. King, R. P. Hammond, J. A. Leary, M. E. Bunker, W. R. Wykoff. Gas recombination system for a homogeneous reactor, NUCLEONICS **11**, No. 9, 25 (1953)
3. S. Katcoff, private communication
4. N. Sugarman, private communication
5. G. E. Challenger, private communication
6. A. S. Newton. Purification of some laboratory gases, MDDC 724 (1947)

TABLE 4—Gas Formation in Reactor with Argon Feed

Experiment	108		112	
Power	25.5 kw		31.7 kw	
Time	303 min		180 min	
Argon feed	5.3 ml/min		5.0 ml/min	
Exit gas	110 ml/min		135 ml/min	
	Before	*After*	*Before*	*After*
Liq. N_2 trap	0.5%	1.5%	0.5%	1.2%
H_2	1.0	0.6	0.0	0.1
O_2	5.2	59.0	1.5	52.2
N_2	18.3	28.4	1.1	23.8
A	75.5	11.5	97.4	24.0

First gross-fission-product kilocurie source designed for utilization studies consists of reactor wastes mixed in concrete to form hollow cylinder. How existing facilities were modified to produce this source from 2,000-curie wastes, how effect of source geometry on 10^4 r/hr dose rate was calculated, is told in this eighth installment of a series

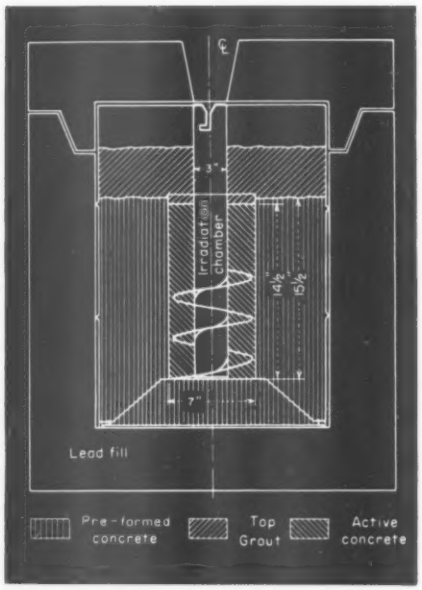

FIG. 1. Source container in 30-gal drum positioned in lead-filled shipping container

RADIATION STERILIZATION VIII

Fission Product Kilocurie Source: Preparation, Radiation Intensity

CONSIDERABLE EFFORT has been directed toward the problem of finding methods for utilization of the ionizing power of the mixed fission products in the waste streams of AEC chemical separations plants. This article describes the preparation at Argonne National Laboratory of the first experimental source using waste gross fission products. This source contains about 2,000 curies of mixed fission products having an average age of about 1 yr; these were obtained from the waste stream of an experimental program undertaken early in 1953 at this laboratory.

The radiation source was prepared in the form of a hollow cylinder with the fission products incorporated in the concrete structure. The gamma dose rate, as measured by chemical dosimetry, is about 10^4 r/hr.

In addition to actual measurements of the gamma dose rate, it was deemed desirable to investigate mathematically the radiation dose rate to be expected from fission products distributed homogeneously in the solid medium surrounding the central cavity. For this type of geometry, a study was made of the effects on radiation intensity at a point on the axis of the cavity of varying (1) the cavity radius, (2) the outside radius, (3) the cylinder height, and (4) the energy level of the emitted radiation. The effect of varying the height above the cylinder bottom of the point receiving the radiation was also examined.

The fission-product source has been shipped to S. A. Goldblith of the Food Technology Department, Massachusetts Institute of Technology, where it will be used to study food sterilization and to compare the physical characteristics of this type of source with other radiation sources as a means of producing ionization.

RADIATION SOURCE made of waste fission products in concrete is stirred by spiral inner column

CHEMICAL DOSIMETER is lowered into fission-product source. Plug in cover of lead shield has been taken out, is suspended above source pot

1. Preparation of the Radiation Source

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For experimental purposes, it is desirable to produce as high a dose rate as possible. It was clear early in the program that there was available, by using the liquid wastes on hand and the existing equipment without major design changes, only sufficient activity to produce a source of, at most, 5×10^4 r/hr under optimum conditions. Plating out of activity on equipment made the attainment of this figure highly uncertain.

The radiation cavity was required to be a cylinder 3 in. in diameter, and the active length was to be 9 to 14 in. The over-all size of the source suggested was such that it would fit into already existing shielded caves at MIT; however, this size could not be produced without major design changes in the equipment. Consequently, it was planned to provide the source in a self-shielded shipping unit capable of re-use.

General Considerations

The source was prepared in equipment originally designed as a waste disposal system. This equipment, known as the Solidification Cell, provides for making concrete out of radioactive solutions in 30- or 55-gallon drums by remote manipulation. Logic dictated that the source should be contained in as small a volume as possible for maximum intensity, and it was decided to use only a small portion of a 30-gal drum for the active concrete; the remainder of the space was to be filled with inactive concrete beforehand. The exact dimensions of the active pour, which were dictated partially by equipment geometry, were selected on the basis of calculations that are discussed later.

Plans called for positioning a small 7-in. diameter stainless-steel cylindrical can in the drum, pouring "cold" concrete around the can, introducing the concentrated fission products into the can, neutralizing, and adding cement. The height of the can was made sufficiently large, $15\frac{1}{2}$ in., to allow for the least possible concentration that could be expected from the volume reduction step plus the greatest volume increase calculable from the lime and cement addition. After setting of the "hot" concrete, a grout was to be poured over it for approximately 6 in. to minimize possible spreading of radioactivity by any dusting, flaking, or chipping of the "hot" concrete during use.

Carrier Design

The source carrier has been designed both as a shipping container and as the primary working shield for use during the experimental program. It consists of three components: the container, the lid, and a small tapered plug in the lid for easy access to the sample cavity. To assist in shipping the assembled unit, a yoke was designed that also serves as a seal during transportation. Shield thickness is 5 in. and consists of lead and structural steel. A diagram of the shield that also shows the location of drum, active concrete, and sample cavity appears in Fig. 1.

Concentration of Wastes

First step in the preparation of the source was to concentrate the available wastes from a stored volume of 400 liters to about 4 liters. This was done in existing equipment by employing a unit originally designed and built to process large volumes of radioactive wastes both for recovery of acid and for concentration of these wastes to a min-

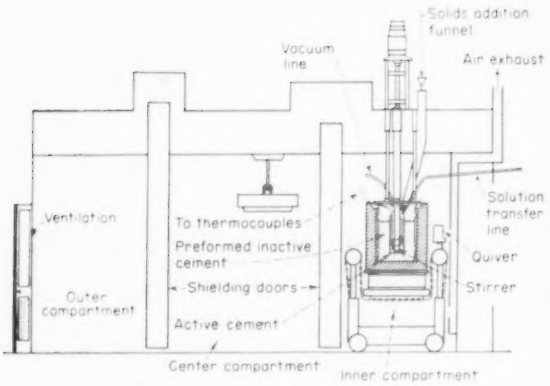

FIG. 2. Solidification Cell arrangement and equipment

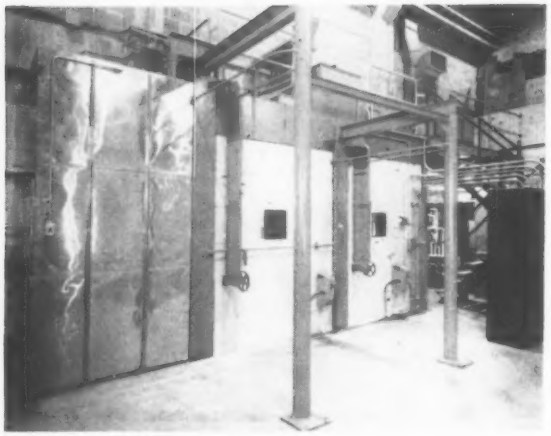

FIG. 3. Exterior of Solidification Cell

imum volume. The acid evaporator and auxiliary equipment are located inside an 18-in.-thick concrete cell 9 × 6 × 15 ft high. This cell is ventilated to remove fumes and airborne activity.

The process equipment used is constructed largely of type-347 stainless steel and is of fairly conventional design. It consists of a steam stripper, a still pot, and a ceramic Raschig-ring-packed rectification column. Decontaminated acid is taken overhead, and the fission products are concentrated in the still from which they can be transferred to the Solidification Cell.

Solidification of Wastes

The source was finally prepared in the modified Solidification Cell. This unit was originally designed and constructed to process the aqueous high-level radioactive wastes produced by the Laboratory by immobilization in concrete (See Fig. 2). It was designed to handle either 55- or 30-gal drums of wastes that, when set, can be conveniently stored. An exterior view of the cell is shown in Fig. 3.

The unit is constructed in an 18-in.-thick concrete cell whose dimensions are 22½ ft long, 6½ ft deep, and 8 ft high. It opens on one end and is capable of being subdivided (by sliding steel doors) into three distinct compartments, each of which has its specific function. The first or outer compartment is kept free of radiation contamination and can, therefore, be entered to perform such manual operations as are required. Operations in the other two cells are remotely controlled. The center compartment is used as an isolation chamber and a waste transfer area, i.e., radioactive wastes are brought into this cell for transfer to the inner cell. In the center cell also, are provisions for removing the lid from the lead-shielded assembly containing the source.

The inner compartment contains the major working portion of the unit, as shown in Fig. 2. Here a flange supported from the ceiling has provisions for an agitator, liquid-level device, a solution entry line, a solids addition pipe, a thermocouple, and a vacuum line. Mounted on the wall are cooling and hydraulic lines used in conjunction with the lead pot containing a steel drum into which the active wastes are drawn, neutralized, and solidified. Both the center and inner cells are provided with laminated plate glass windows for viewing the operations.

The lead-shielded pot into which the steel drums fit is mounted on a four-wheel movable-bed dolly. For positioning purposes, two wheels on one side run in a track, simplifying the remote positioning problem to one of alignment one way instead of two.

In preparation of wastes for disposal the pot is wheeled into the center cell, the lid removed, and the pot moved to the inner cell. After being positioned, the pot is raised (and later lowered) by means of two hydraulic pistons to effect mating of flange and drum.

Next, the cooling water lines are connected, vacuum is applied to the drum, and the radioactive wastes are drawn into the drum from another container located in the center cell. The liquid level device (electrode) is used to determine the volume, and the solution is neutralized.

Neutralization of caustic wastes is effected by blending with acidic wastes. The usual wastes are acidic, and these are neutralized by lime addition. Lime addition is accomplished by means of a standard screw feeder through a milker (to prevent the spread of airborne contamination into the working area) to the drum. During neutralization, agitation is applied, and cooling water is circulated as needed to an annulus between lead pot and drum.

Neutralization is followed by cement addition, again using the screw feeder, until sufficient cement is added to satisfy a 0.6 ratio of cement weight to neutralized-solution weight. Stirring action is continued, after which the cooling lines are disconnected and the pot lowered. A drip pan is placed under the flange to prevent contaminated material from dripping on the pot or floor.

After the cement has hardened, the pot is re-positioned under the lid and raised to receive the lid. Next, the pot is lowered, uncoupled and wheeled outside for transportation to storage. The drum is removed from the lead pot and stored, and the empty lead pot is returned for re-use.

In preparing this kilocurie radiation source, some modifications were made in the equipment just described. For example, it was deemed advantageous to use a hollow stirrer with a continuous helical ribbon surrounding it. This stirrer would disengage from the main agitator shaft and remain imbedded in the "hot" concrete. Such equipment proved satisfactory.

After a decision had been made to reduce the dimensions of the radioactive concrete, it became necessary to feed

the liquids and solids into a container of only 7-in. inside diameter instead of 18½-in. inside diameter, and changes were necessary, therefore, in the flange components. A smaller solids addition line was required to insure the accurate placing of the lime and cement. Stainless-steel tubing of ⅜-in. diameter was used for this purpose, with a conduit "fishline" supplying the motive power for the solids; the screw feeder and milker were thus eliminated.

Since the liquid-level electrode had also been discarded, it was decided to calibrate the stirrer. This was done by using milk of lime as paint, with the expectation that the lime would react with the acid, leaving a sharp line of demarcation. Such proved the case.

With these modifications the waste disposal unit was converted to allow production of the source.

Operations

Some 410 liters of liquid wastes containing gross mixed fission products that had been stored for nearly one year in lead-shielded pots were available as feed for the concentrator. This was fed to the concentrator continuously at a rate of 6 l/hr for about 75 hr, while the still volume was maintained fairly constant at 10 l. The final 10 l were then further concentrated to about 3 l for an over-all concentration factor of about 120. It had originally been hoped to achieve a concentration factor of about 200, but the danger of salt formation and continued telegage plugging upon further concentration was too great.

A lead-shielded ⅜-in. stainless-steel transfer line interconnecting the volume reduction unit and the Solidification Cell was heated by means of a steam coil to minimize the danger of salting out during the liquid transfer.

The lead-shielded carrier containing the 30-gal polythene-lined drum with its pre-formed "cold" concrete was properly positioned against the sealing flange, vacuum was applied, and the proper valves were opened. The flow of concentrate through the discharge line was easily monitored. Several minutes of suction were required to draw over a portion of the concentrate, but because of inoperative telegage lines the quantity was not known. Backwashing the discharge line with water reduced the line radiation by a factor of about 20.

The agitator used in stirring the concentrate during and after the solids addition was previously calibrated and was painted with milk of lime along its length in measured half-inches so that the liquid height could be determined fairly accurately by reaction with the acidic concentrate. By dropping the carrier and observing the agitator through the shielding window, it was determined that 2.65 l of concentrate had been transferred. Accurate knowledge of this figure was important, because it determined the degree of concentration necessary in the wash out of the volume reduction unit, as described in the next paragraph.

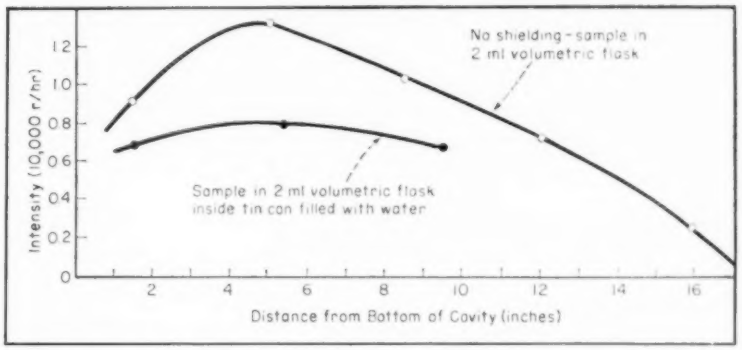

FIG. 4. Dose rate curves inside source obtained with ferrous-ferric dosimeters

The still was then charged with 10 l of a solution that was 0.02 *M* in HF, 0.25 *M* in HNO_3, and 0.02 *M* in $Al(NO_3)_3$. This solution, which is particularly useful in removing salts of zirconium and niobium from stainless steel with only moderate corrosion of the equipment, was boiled down to a volume of about 2½ l and transferred to the Solidification Cell, where the final volume was determined to be 5 l.

Agitation was applied, and neutralization with lime was begun. The resultant temperature rise was observed by means of two iron-constantan thermocouples welded into the receptacle. Lime was slowly added until no further rise in temperature was detected, at which time 1.20 kg of lime had been added. Using 0.55 as the weight ratio of cement to neutralized solution, 3.85 kg of cement were added over a 3-hr period. (The weight ratio of 0.55 was used to preclude premature setting of the concrete.) Agitation was continued for 45 min to insure homogeneity.

In 4 hr the cement had hardened sufficiently to allow disengaging the stirrer from the motor shaft, and the pot was then lowered. After several days allowance for hardening, the top grout was poured and given time to set. The pot was moved and re-positioned under the lid, raised to receive the lid and plug, and lowered. The outer cell doors were opened, and radiation readings were taken of the pot periphery. These readings were remarkably constant over the portion in line with the "hot" concrete, ranging from 70 to 75 mr/hr.

Dosimetry

With the assistance of E. J. Hart of the Chemistry Divison of ANL, the radiation level throughout the sample cavity was investigated by chemical dosimetry before shipment of the source to MIT. The standard ferrous-ferric reaction was used (*1*). Preliminary investigations using samples centrally located in the sample cavity gave a curve (Fig. 4) indicating a maximum intensity of 1.34×10^4 r/hr at a point 5 in. from the bottom of the cavity. The intensity varies by a factor of two from 0 to 5 in. and from 5 to 12 in., denoting that the source is not completely homogeneous; however, the uniformity is reasonably good over the bottom 12 in.

A flatter intensity response curve (Fig. 4) was obtained by inserting a ferrous sample inside a water-filled tin can; however, the maximum intensity dropped off to 0.8×10^4 r/hr.

Samples were also irradiated inside aluminum pipe lengths. Inside an aluminum pipe of 0.023-in. wall thickness, the dosage was 8.8×10^3 r/hr; inside two segments having a combined wall thickness of 0.297 in., it was 8.5×10^3 r/hr; and inside three segments having a combined wall thickness of 0.444 in., it was 7.7×10^3 r/hr. This indicates an effective average energy of about 0.4 Mev.

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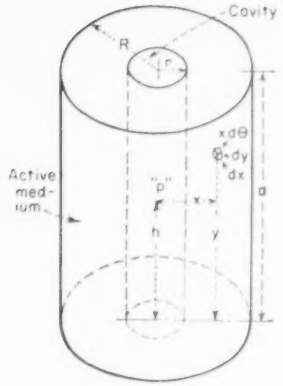

FIG. 5. Hollow cylindrical source with mathematical quantities noted

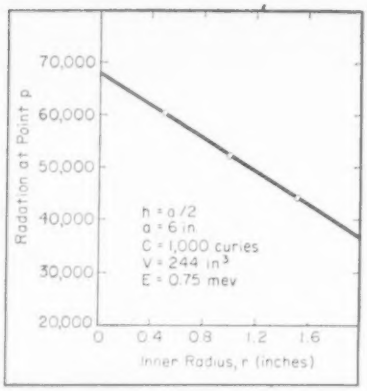

FIG. 6. Effect of inner radius on activity level

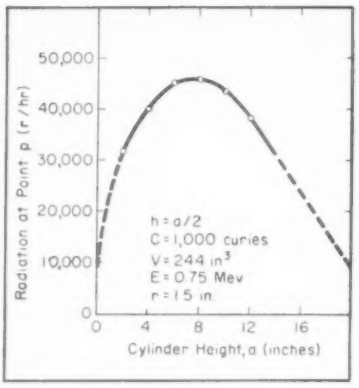

FIG. 7. Effect of cylinder height on activity level

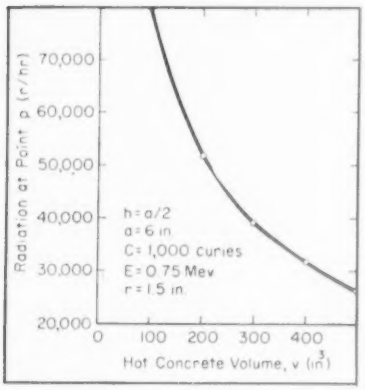

FIG. 8. Effect of "hot" concrete volume on activity level

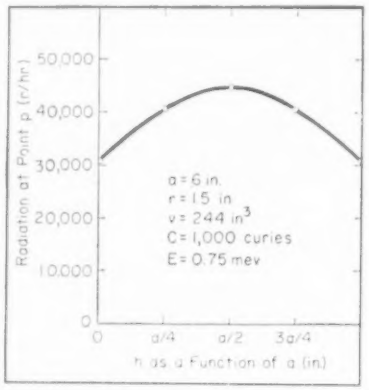

FIG. 9. Variation of activity level along vertical axis of cavity

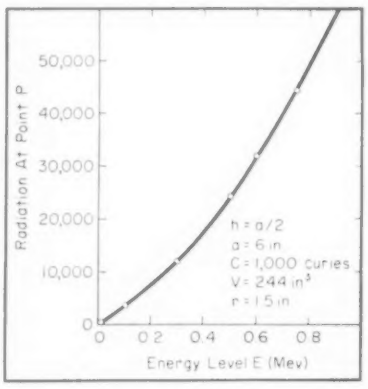

FIG. 10. Effect of energy level on activity level

2. Calculations of Radiation Intensity

By I. G. DILLON, L. BURRIS, and W. A. RODGER
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To establish the optimum geometry for a hollow cylindrical source, a mathematical study was made of the effects of variations in source geometry and energy (Mev) on the radiation intensity along the center line of the cavity in the source.

Equation 1, derived at the conclusion of this article, gives an estimate of the radiation intensity at any point on the center line of a hollow cylindrical source (Fig. 5). Variation of intensity within the radiation cavity has been discussed previously by Crean *et al.* (2)

$$I_p = 864C'E \int_0^a \int_r^R 2\pi x c \frac{2.3^{\frac{(x-r)}{(x)}\sqrt{x^2+(y-h)^2}}}{T} \frac{dx\,dy}{x^2+(y-h)^2} \quad (1)$$

where I_p is the radiation level in r/hr at point p along the axis of the hole; h, a, r, R, x and y are distances in inches (Fig. 5); C' is curies of gamma activity of given initial energy per unit volume; E is energy of activity in Mev; and T is the tenth-thickness of the fission product medium.

Equation 1 has been solved by graphical integration and by the use of the IBM computer operated by the Physics Division of ANL. The effect of variations of source geometry are shown, and the dependence of radiation intensity on average energy is also indicated.

The accompanying figures reveal the effect of changing geometry. Figure 6, in which radiation intensity is shown to be essentially inversely proportional to the radius of the sample cavity, indicates the desirability of keeping this dimension as small as experimental conditions will allow.

Figure 7 illustrates the effect of cylinder height on radiation intensity, and as would be expected, the graph shows an optimum (maximum) intensity at a finite cylinder height. (*Cont. on p. 20*)

Comparison of Methods for Calculating Radiation Intensities

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The calculation of a dose rate from a hollow cylindrical source in this article is based on assumptions similar to those used by Lewis *et al.* (*5*). However, the authors feel that the calculations presented here are much simpler and more accurate for wide ranges of variables than those presented by Lewis.

For example, the equation presented by Lewis for dose rate from a hollow cylindrical source of negligible thickness involves elliptical integral functions. The following derivation shows such complexity is unnecessary for radiation received at a point p along the vertical axis of the cylinder cavity

$$dI_p = \frac{864CE}{A} \int_0^{2\pi} \int_0^L \frac{r\,d\theta\,dZ}{(Z-h)^2 + r^2}$$

where I_p = dosage at p (r/hr), C = total activity (curies), $A = 2\pi rL$ = inside surface area of hollow cylinder (in.^{2}), L = cylinder height (in.), E = energy of radiation (Mev), r = cylinder radius (in.), Z = height above cylinder base parallel to vertical axis (in.), and h = height of point p above cylinder base (in.).

Integrated with respect to θ, this equation assumes the form

$$I_p = \frac{864CE(2\pi r)}{A} \int_0^L \frac{dZ}{Z^2 - 2Zh + h^2 + r^2}$$

which has the exact analytical solution

$$I_p = \frac{864CE(2\pi r)}{2\pi rL} \left[\frac{1}{r} \left(\tan^{-1} \frac{L-h}{r} - \tan^{-1} \frac{-h}{r} \right) \right]$$

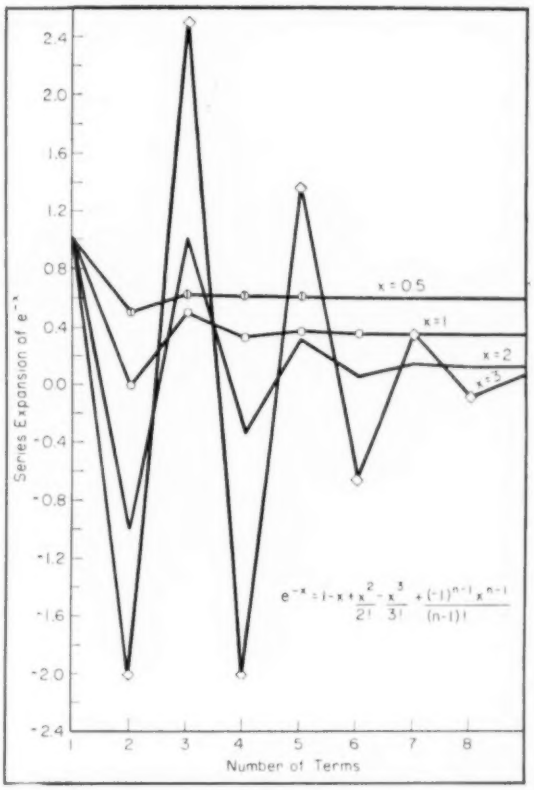
Simplifying and collecting

$$I_p = \frac{864CE}{rL} \left[\tan^{-1} \frac{L-h}{4} - \tan^{-1} \frac{-h}{r} \right]$$

Thus, whereas the solution of Lewis for a sheet source is more general, it is quite complicated for use by those who do not have an extensive mathematical background. The relatively simple solution described will suffice for most applications.

In the case of a hollow cylindrical source of finite wall thickness, the general equation

$$dI = \int_{\theta=0}^{\theta=2\pi} \int_{r=r_1}^{r=r_2} \int_{Z=0}^{Z=L} \frac{Vr\epsilon^{-\mu\rho/r-r_1|\csc\phi}}{(Z_1 - Z)^2 + r^2} dZ\,dr\,d\theta$$



BEHAVIOR of series expansion of e^{-x}

was solved by Lewis by expanding the exponential as an infinite series and assuming convergence in three terms. This is a good assumption where the ratio of outside to inside radius of the cylinder (r_2/r_1) is near to unity or where $((Z_1 - L)/r)$ is small. However, for ratios of $(r_2/r_1) > 3$ and/or $((Z_1 - L)/r)$ such that the value of the exponent x exceeds 1.0 (see illustration at left), the series converges very slowly and erratically, leading to large errors in the expansion outlined by Lewis. The IBM or graphical integration of Eq. 1 in this article is as rapid as the evaluation of the multiterm series expansion by Lewis and is free from the aforementioned pitfalls. Graphical integration of Eq. 1 gives the correct result. For a single calculation it may be more tedious than the series expansion of Lewis, but multiple calculations can be made relatively rapidly since many operations are repeated. When a large number of determinations are required, it is highly advantageous to be able to set up the calculation on a computer.

Figure 8 demonstrates the variation of intensity as the volume of the source cylinder is varied. Since in this calculation the height and inside radius were held constant, this plot in effect shows the variation with outside radius. Clearly the volume must be held to a minimum. The y-intercept gives the intensity at zero volume, i.e., when all the activity is plated on the cavity wall, and thus represents the maximum intensity obtainable from a given geometry.

Figure 9 depicts the variation of radiation intensity along the vertical axis of the hole, showing that intensity under the conditions given varies by only 50% from top to bottom.

A plot of radiation intensity versus energy of radiation (Fig. 10) gives a curve slightly concave upward. One thousand curies of 0.1-Mev gamma radiation would give a radiation intensity less than 0.1 that provided by 1,000 curies of 0.75-Mev gamma radiation.

Equation 1 has been evaluated only for the specific case of dispersion of source material in concrete in a cylindrical shape. However, the principles as shown in the derivation can be applied to other shapes and other materials. Tenth-thickness values used were taken from data of H. M. Glen (3).

Derivation of Equation

The intensity of radiation from a point source with no intervening shielding material is (4)

$$E_a = \frac{\mu S_p}{4\pi a^2} \qquad (2)$$

where E_a = energy in ev/sec absorbed per cm³ of air at 1 cm; S_p = source strength in ev/sec = curies (C) $\times$ 3.7 $\times$ 10^{10} (dps/curie) $\times$ E(Mev)/disintegrations $\times$ 10^6(ev)/Mev; a = distance in cm; and μ = recoil absorption coefficient for air = 3.5×10^{-5} per cm.

Conversion of E_a from ev/sec per cm³ of air to r/hr (which is the number of electrostatic units per cm³ of air at standard conditions per hour) requires multiplication by $^1/_{3.2}$ ion pairs per ev, by 4.8×10^{-10} ion charge per ion pair, by 3,600 sec/hr, and, if a is in inches, by $1/2.54^2$, giving

$$I_a = \frac{864CE}{d^2} \qquad (3)$$

where I_a is radiation intensity in r/hr; d is distance in inches; and C is total curies.

A parallel beam of radiation having a given energy will, in traversing a layer of substance, be reduced in intensity by a constant fraction σ per centimeter, or

$$\frac{I}{I_0} = e^{-\sigma t} \qquad (4)$$

where t = thickness of layer in centimeters, and I_0 = intensity of incident radiation, or

$$\frac{I}{I_0} = 10^{-\frac{t}{T}} \qquad (5)$$

where T is the tenth-thickness of the absorbing media.

A small differential volume of concrete located as shown in Fig. 5 and having the dimensions $(dx)(dy)(xd\theta)$ would act essentially as a point source. This volume when multiplied by C'', the curies per unit volume of material, gives the total curies in this small amount of material. The distance from the differential element to the point p, where the radiation intensity is desired, is $\sqrt{x^2 + (y-h)^2}$, and the thickness of absorbing medium traversed is $\left(\frac{x-r}{x}\right)\sqrt{x^2 + (y-h)^2}$. Combining these terms and integrating over the entire volume gives

$$I_p = 864C''E \int_0^a \int_r^R \int_0^{2\pi} \frac{x}{x^2 + (y-h)^2} 10^{-\frac{\left(\frac{x-r}{x}\right)\sqrt{x^2+(y-h)^2}}{T}} d\theta dx\, dy \qquad (6)$$

Integrating with respect to θ gives

$$I_p = 864C''E \int_0^a \int_r^R \frac{2\pi x 10^{-\frac{\left(\frac{x-r}{x}\right)\sqrt{x^2+(y-h)^2}}{T}}}{x^2 + (y-h)^2} dx\, dy \qquad (7)$$

and converting from logarithmic base 10 to base e gives

$$I_p = 864C''E \int_0^a \int_r^R \frac{2\pi x e^{-\frac{2.3\left(\frac{x-r}{x}\right)\sqrt{x^2+(y-h)^2}}{T}}}{x^2 + (y-h)^2} dx\, dy \qquad (1)$$

Conclusion

The source discussed here should prove to be a valuable addition to the experimental efforts being directed toward fission-product utilization. It is emphasized that this is not the most ideal way to make up a fission product source, since introduction of absorbing material is undesirable. This method of production was adopted in this case, however, because equipment was available which with some modification could be used to produce a source more quickly.

* * *

The authors wish to express their appreciation to a large number of the staff members at Argonne National Laboratory who have given valuable assistance in this program, particularly to: W. R. Walters, J. H. Schraidt, A. J. Shor, P. D. Franson, N. Bohlin and R. Blomgren for their work in the design and construction of the Solidification Cell; O. J. Du Temple and J. Casler for design assistance with the volume reduction equipment; J. V. Natale, A. A. Chilenskas and P. Fineman for assistance in setting up and operating the equipment involved; L. F. Coleman for assistance in deriving the equations and to N. F. Morehouse, Jr. and Jean F. Hall for assistance in setting up the data for solution on the IBM machines; and to S. Lawroski, director of the Chemical Engineering Division, for advice, encouragement and over-all direction of this project.

BIBLIOGRAPHY

1. C. J. Hochanadel, J. A. Ghormley, *J. Chem. Phys.* **21,** 880 (1953)
2. L. E. Crean, P. J. Isaacs, G. J. Weiss, F. Fahnoe, NUCLEONICS **11,** No. 12, 32 (1953)
3. H. M. Glen, Introduction to nuclear shielding for engineers, ORNL-CF-51-10-221 (1952)
4. G. W. Morgan, Some practical considerations in radiation shielding, Circular B-4 (Isotopes Division, U. S. Atomic Energy Commission, Oak Ridge, Tenn., 1949)
5. J. G. Lewis, J. V. Nehemias, D. E. Harmer, J. J. Martin, NUCLEONICS **12,** No. 1, 40 (1954)

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Which I^{131} Counting System Is Best for Laboratory Use?

THESE DATA . . .

Instrument	Background (cpm)	Standard samples* (cpm)	Efficiency (%)	Minimal detectable activity: Times background	Minimal detectable activity: $\mu c \times 10^{-6}$	Minimal detectable activity: Standard error†	Minimal detectable activity: Counting time (min)
Well-type scintillation counter	140	3,260	48	1.2	26	8	60
End-window G-M counter	24	1,760	25	1.4	16	10	60
Windowless G-M counter	38	3,150	46	1.2	8	13	90
Windowless proportional counter	58	3,180	46	1.2	11	10	90

* Each set of samples was prepared with 100 μl I^{131} NBS standard containing 6,850 dpm.
† Standard error of the net counting rate used in calculating the minimal detectable radioactivity.

. . . show that windowless counters have efficiencies equal to a well-type scintillation counter. Simpler and more convenient sample preparations, however, favor the scintillation counter for laboratory use

By JOHN H. WEISBURGER and HARRY J. LIPNER*
National Cancer Institute
National Institutes of Health
Bethesda, Maryland

THE GENERAL AVAILABILITY and widespread use of the iodine isotope I^{131} in laboratory research has made it desirable to investigate the relative efficiencies of various counting systems for such isotopes. It is the purpose of this article to compare the maximum efficiency obtainable with a Geiger-Müller (G-M) end-window counter, a windowless gas-flow counter operating in the G-M and proportional regions, and a well-type scintillation counter; the instruments used were commercially available models.

While a number of studies have recently appeared (*1–3*), the efficiencies reported were not obtained under conditions of optimum geometry. In clinical work (*1, 2*), the radiation from the source was highly collimated by suitable shields and the counter was located at relatively great distances from the source. Various positions around the patient had to be scanned in as short a time as possible. This imposed geometrical limitations on the efficiency and minimized the amount of radiation detectable with a given error. In these cases, as well as in the work of Bruner and Perkinson (*3*), the maximum efficiency of the counting system was not secured because of the different emphasis on positioning of the counter with respect to the source. On the other hand, under laboratory conditions it is possible to select or design equipment and geometry for optimum efficiency. Also, smaller amounts of radiation can be estimated with a predetermined error by extending the counting time.

Sources Used

The sources used in our work were prepared with a National Bureau of Standards sample of I^{131} containing an accurately known absolute activity (disintegrations per second) per unit volume. Although this solution was alkaline when received, progressive loss of activity occurred when aliquots

* Public Health Service Research Fellow of the National Cancer Institute.

were plated on aluminum or glass disks. This decrease in activity was prevented* by mixing the active iodide solution on the plate with a solution containing 50 μg of silver nitrate per plate. The water was then removed under a gentle stream of warm air (hair dryer) (*4*).

For the G-M counters, 100 μl was plated, a number of replicate plates being prepared. Similarly, 100 μl of the standard solution was pipetted into the 1-dram vials used with the scintillation counter. No silver nitrate was added in this case, since there was little possibility of loss of activity from the solution in the tightly closed vial.

Self-absorption corrections, in the case of the plates used in the G-M counter, were not made since the amount of solid material per plate was so low as to be practically invisible. Similarly, the activity per plate was low enough so that coincidence corrections were insignificant.

Correction for background. Whereas a counting error of 1–2% can be readily achieved in a reasonable time with samples of moderate or high activity, it is usually sufficient to strive for an accuracy of ±10% on plates of low activity. In actual practice, depending on the background counting rate of the system, such an accuracy can be obtained when the total counting rate (sample + background) is 1.2 to 1.4 times the background rate. Thus, the net counting rate can be evaluated with an acceptable 10% error when this rate is 20–40% of the background rate. Obviously, relatively long counting periods, from 30 to 180 min, are required for such extreme cases. It is also necessary to be located in a quiet electrical and background environment. The average background counting rate should remain fairly constant, without abrupt variations, within the stated limits of error over the total counting period.

The variations in background counting rate were investigated over 15-hr periods (overnight) in two of our counting systems by means of a ratemeter and continuous recorder connected in parallel with the scaler circuit. The trace showed short-term changes in 5–10 min cycles where the variation from the mean amounted to approximately 5–10%. Superimposed on this was a long-term (2–4 hr) downward or upward trend, which may have been caused by circuit variations.

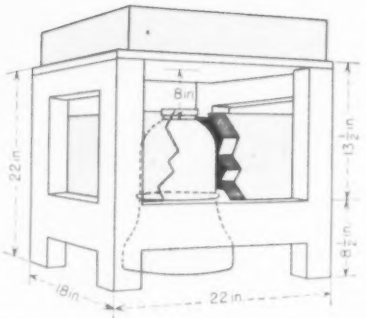

FIG. 1. Well-type scintillation counter and lead shielding supported by table

A satisfactory average background counting rate can be determined, despite the variation in background, if the counting period is sufficiently long. Depending on the total number of counts collected, a net rate that is only a fraction of the background rate can thus be determined with sufficient accuracy for this type of work. In the discussions of the individual counters used in our laboratory, the smallest amount of radiation detectable by each is given as that quantity that can be assayed with an error of about 10%. All results obtained are corrected for decay of the isotope by relating all data to a determined time.

Scintillation Counter

Conditions of optimal geometry can be attained with a well-type counter, the prototype of which was described by Anger (*5*). In this survey, a commercial version of such an instrument† was used.

The crystal in our instrument accommodates tubes or vials up to 16 mm in diameter; the manufacturer‡ states that the well is 1½ in. deep, $\frac{19}{32}$ in. in diameter.

The background counting rate of the scintillation counter, with the 2-in. lead shield provided, was 380 cpm in our laboratory. This background was reduced to about 140 cpm by surrounding the counter with an additional 4 in. of lead on the sides, 6 in. of lead on a platform 8 in. above the opening into the counter (Fig. 1), and 4 in. of lead supporting the entire assembly.

The major advantage of this instrument is the extreme simplicity of sample preparation. Thus, where histological studies are desired, the weighed tissue is dropped into 0.1–0.3 ml of fixative, and the activity determined directly. Conical centrifuge tubes (15 ml) are as satisfactory as round-bottom test tubes or flat-bottomed vials. The results obtained on equal aliquots (0.1 ml) of the same solution of NaI^{131} were 1,170, 1,130 and 1,130 cpm for vials, conical centrifuge tubes and 16-mm-diameter round-bottomed test tubes, respectively. The effect of increasing sample volume on the counting rate is shown in Fig. 2. Over the range of 0.1–2.8 ml, the decrease in the counts detected was only 4.5%.

Efficiency. The efficiency (counts recorded/absolute disintegrations) of the scintillation counter was 48%, as determined with a National Bureau of Standards sample of I^{131}. Recent reports (*6, 7*) also cite an efficiency of this order.

A simple calculation (*8*) gives the level of the minimal detectable radioactivity under our conditions. For a 30-min count with a background of 140 cpm, the standard deviation of this rate is ±2.12. Assuming the sample being counted has an activity 20% greater than background, the gross number of counts per minute would be 168 (net count, 28 cpm) with a standard deviation of ±2.4. The standard deviation of the net count would be 3.2 with a consequent error of 11%. An increase in counting time to 60 min would reduce the error to 8%. Hence, the minimum radioactivity detectable is 28 cpm or 26×10^{-6} μc.

End-Window G-M Tube

A conventional thin-window (1.9 mg/cm²) tube¶ was mounted in the holder of a 1½-in.-thick lead shield§ in such a manner that the distance between the window and the top of the aluminum plates (1⅛-in. diameter, $\frac{1}{16}$-in. thick) was 3.5 mm. This was the minimum distance permissible to

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* Suggested to us by H. H. Seliger, National Bureau of Standards.

† Nuclear Instrument and Chemical Corp. (Chicago, Ill.), Model DS-3. This model utilizes a well-type crystal enclosed in an aluminum can, except for the glass-covered bottom, which is mounted on a DuMont K-1186 photomultiplier tube. The signal from the latter is amplified in two stages by a built-in triode-pentode 6U8 tube before being passed on to a commercial scaler.

‡ The Harshaw Chemical Co., Cleveland, Ohio.

¶ Type TGC-2, Tracerlab, Inc., Boston, Mass.

§ Model AL-14-A, Technical Associates, Glendale, Calif.

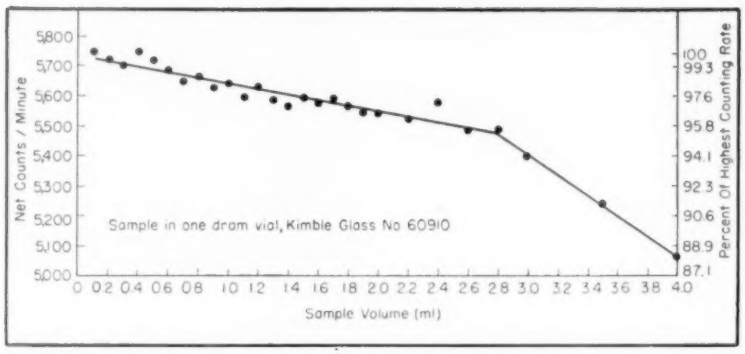

FIG. 2. Counting rate as a function of sample volume

allow convenient insertion and removal of the sample holder. Conditions of maximum possible geometry, and hence efficiency, were obtained in the physical arrangement used. The output from the G-M tube was connected to the input of a commercial scaling circuit.

The scintillation counter responds exclusively to the γ-rays of the isotope. The G-M counter primarily detects the β-rays of I^{131}, while the γ-rays contribute only slightly. Therefore, self-absorption corrections are required for any source that cannot be considered infinitely thin.

Sample preparation. Sample preparation with this instrument is in general more complex than with the scintillation counter. In its simplest form, this preparation consists in pipetting a solution onto a planchet and evaporation of the solvent. In its more complex form, sample preparation involves the reduction of a solid sample to a fine powder, the suspension of this powder in a volatile solvent, the delivery of an aliquot of the suspension to a plate or cup, evaporation and weighing.

The G-M counter, under these conditions, was 25% efficient, as determined with aliquots of the NBS I^{131} sample. The minimal detectable radioactivity, calculated on the basis of a sample 40% above background counted for 60 min, would have a net count of 9.4 ± 1.0 cpm. The minimal detectable activity, therefore, is 16.4×10^{-6} μc.

Gas-Flow G-M Counter

A commercial version* of a windowless flow counter and automatic sample changer described recently (*9*) was used. The sample-preparation technique used for the end-window counter also applies to this instrument and need not be discussed further.

Efficiency. An efficiency of 48% was obtained in this instrument with the soft β-emitter carbon-14.

An efficiency of 46% was recorded with the NBS I^{131} sample when the activity was plated over the entire area (11.5 cm^2) of the glass plates normally used with this counter. When a point source was prepared with the same amount of activity, the efficiency was 50%, probably owing to slightly improved geometry. An essentially similar efficiency resulted when aluminum plates were used as support for the activity. This finding was not unexpected since the backscattering factor (related to the Z number) for glass and aluminum are similar.

With the background of 38 cpm of this instrument, an activity 20% above background (7.6 cpm) can be counted with a standard error of 12.8% in about 90 min when the Autoscaler used with the counter is set to collect 4,096 counts. This counting period is not excessive for laboratory work since the operation of this system is automatic and overnight counting is feasible. The minimum detectable amount of activity is therefore 8 cpm or about 8×10^{-6} μc.

No essential difference in efficiency was encountered between the windowless G-M counter and a windowless proportional counter.† Two identical plates each gave 466 cpm on the windowless G-M counter, and 472 cpm on the proportional counter. At these moderate counting rates, therefore, the counters have practically equal efficiency. On the other hand, Graf, *et al.* (*10*) reported a 20% higher efficiency for the proportional counter. Owing to the higher background rate of the proportional counter, averaging 58 cpm, the least amount of activity detectable, as defined in our previous discussion, is slightly higher in this counting system.

* Beta Raytor, Beta Instruments, Palo Alto, Calif.

† Mark 12 Model 1, Radiation Counter Laboratories, Chicago-Skokie, Illinois, connected to a linear amplifier-high voltage supply, RCL Mark 15 Model 1, and this in turn feeding a scaler. The counting gas was methane.

Conclusions

The data summarized in the table on page 21 show that the windowless gas-flow counters and the scintillation counter have comparable efficiencies of 46–48%, while the thin-window G-M counter is slightly more than half as efficient as either of the other counters. When very low activity samples are to be counted, the higher background of the scintillation counter makes it no more advantageous than the other counters examined.

The difference in levels of detectable radioactivity among the various counters is not as large as might be predicted on the basis of either background or efficiency. The greater reproducibility of counts with the scintillation counter, because of the elimination of self-absorption effects and variations ascribable to sample preparation associated with β-counters, allow the reliable determination of amounts of activity of almost the same order of magnitude as with other counters. For β-γ emitters like I^{131}, the scintillation counter seems to be a useful and desirable instrument. In those laboratories, however, where economic factors play a role in the selection of counting systems, a simple G-M tube used under appropriate conditions ensures relatively satisfactory results.

BIBLIOGRAPHY

1. W. J. MacIntyre, *Proc. Soc. Exptl. Biol. Med.* **75,** 561 (1950)
2. D. Kohl, Z. Moore, S. Chou, NUCLEONICS **9,** No. 1, 68 (1951)
3. H. D. Bruner, J. D. Perkinson, Jr., NUCLEONICS **10,** No. 10, 57 (1952)
4. Frank J. Kelly, C. Thorpe Ray, S. A. Threefoot, G. E. Burch, *J. Lab. Clin. Med.* **36,** 606 (1950)
5. H. P. Anger, *Rev. Sci. Instr.* **22,** 912 (1951)
6. S. A. Berson, R. S. Yalow, S. S. Schreiber, J. Post, *J. Clin. Invest.* **32,** 746 (1953)
7. W. J. MacIntyre, W. F. Wirth, T. E. Fessler, NYO-4018 (1953)
8. G. Friedlander, J. W. Kennedy, "Introduction to Radiochemistry," p. 209 (John Wiley and Sons Inc., New York, 1949)
9. W. N. Nye, J. D. Teresi, *Anal. Chem.* **23,** 643 (1951)
10. W. L. Graf, C. L. Comar, I. B. Whitney, NUCLEONICS **9,** No. 4, 22 (1951)

Effects of angle of incidence, energy, spectrum, development, and film properties on the dosimetric properties of five films are shown. With a thin emulsion and sensitive density measurement techniques, NTB film is an excellent dosimeter

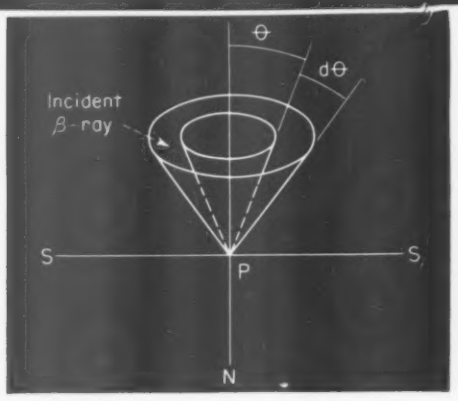

FIG. 1. Geometry of β-ray angular distribution function

Photographic Detection and Dosimetry of Beta Rays

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Photographic film has numerous applications in measurement of beta-radiation dose (*1–3*). Its most distinctive advantage is high spatial resolution, extending down to dimensions of a few microns. Another advantage, in certain applications, is convenience and simplicity. The chief disadvantage is lack of accuracy. This results primarily from the dependence of film response on the energy and angular distribution of the incident beta-radiation, and secondarily from irregularities in the film itself and in the development conditions. This article assesses these limitations for several different emulsions, and suggests methods of overcoming the difficulties. Many of the findings are pertinent also to the dosimetry of X- and γ-rays, whose photographic action is by their secondary electrons, and to nondosimetric problems in beta-ray detection.

SCATTERING, ABSORPTION

In the interpretation of measurements, frequent reference is made to the behavior of β-rays as they pass through matter. Certain special features are summarized in the following sections.

Angular Distribution

The high degree of scattering undergone by beta particles in traversing matter raises problems of angular distribution that are of fundamental importance in β-ray dosimetry. Although this is especially true in the case of photographic detection, since the emulsion is relatively thick in terms of mass per unit area, questions of angular distribution are often ignored in these measurements.

The angular distribution of β-particles incident at a point on a surface may be characterized by the function $dP(\theta)/d\theta$, where $dP(\theta)$ is the fraction of all the incident particles that falls between the angles θ and $\theta + d\theta$ with respect to the normal. The geometry is clarified in Fig. 1. The surface in question is perpendicular to the paper, intersecting it at the line SS. The normal to the surface through point P is the line NN. The particles passing between the two cones of half angles θ and $\theta + d\theta$, respectively, make up the fraction $dP(\theta)$.

The form of the angular-distribution function at the surface SS is determined by both the nature of the source and the thickness of absorber (if any) between source and surface. Three important special types of source should be considered. If the β-particles are emitted from a distant point source, and do not undergo scattering in the intervening space, $dP(\theta)/d\theta$ is infinite at some particular value of θ determined by the geometrical relationship between source and surface point, and is zero for all other values of θ. When the β-rays are emitted from the face of a homogeneous source of "semi-infinite" extent in contact with the surface in question, it can be shown by an argument similar to Brownell's (*4*) that $dP(\theta)/d\theta = 2 \sin\theta \cos\theta$ (this distribution is called "diffuse"). If the source is a thin layer (thickness so small that negligible scattering occurs within the source), $dP(\theta)/d\theta = \sin\theta$.

If sheets of absorber are interposed between the surface SS and the source, in any of these three cases, the angular distribution at that surface is shifted toward an equilibrium pattern that is close to diffuse. The magnitude of the shift increases with atomic number and thickness of absorber. In tissue-like materials, substantially equilibrium distribution will have been reached

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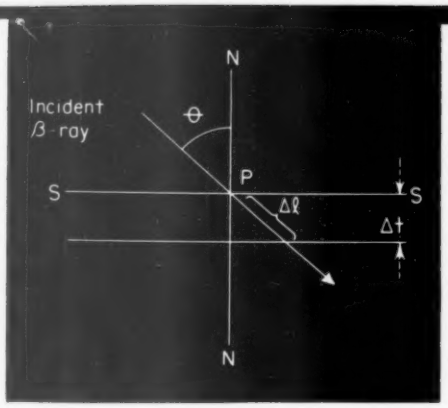

FIG. 2. Dependence of dose at surface on angle of incidence

under absorption equal to roughly one-tenth the maximum range, whatever the initial distribution. The fundamental cause of this shift is that a diffuse distribution at the surface of an absorber is associated with randomness of path orientation inside the absorber, a condition scattering promotes (*4*).

The dose contributed by the incident electrons as they pass through the surface *SS* is dependent on their angular distribution. Other things being equal, the energy dissipation by a single particle in a very thin surface layer is proportional to its path length in that layer. In Fig. 2, the β-particle indicated has a path length $\Delta l = \Delta t/\cos\theta$ in a surface layer of thickness Δt. For a large number of particles, incident at different angles, the total dose D is proportional to the average path length within the layer. That is,

$$D = K \int_0^{\pi/2} \frac{dP(\theta)}{d\theta} \frac{1}{\cos\theta} d\theta$$

Upon substitution of the appropriate angular distribution functions for $dP(\theta)/d\theta$, it is found that for perpendicular incidence, $D = K$; for diffuse incidence, $D = 2K$; and for sin θ incidence, D = infinity. This "infinite" dose has exactly the same validity as the "infinite" dose that is said to occur at a true point source of finite strength.

This analysis shows that if N β-particles/cm^2 diffusely incident on a film do not produce the same blackening as $2N$ perpendicularly incident, the film sensitivity for dosimetric purposes is dependent on angle of incidence. On the other hand, if film is substantially independent of angle of incidence in its response as a dosimeter, it is strongly dependent on angle of incidence in its response as a counter of β-particles/cm^2.

Backscattering

Dosage at the surface of a piece of matter is caused by β-particles as they pass through the surface into the matter and as they pass back out (if they undergo backscattering). The number of β-rays backscattered increases with increasing obliquity of incidence and with increasing Z of backscattering material; however, it is substantially independent of energy for low-Z materials (*5, 6*). For any incident distribution in which the large angles of incidence are not much more predominant than in the diffuse case, the angular distribution of backscattered particles approaches diffuse (*4, 7*). For very oblique incidence, such as the sin θ distribution from a thin plane source, the backscattered angular distribution emphasizes large angles somewhat more than a diffuse pattern (although in the thin plane source example, less than the incident sin θ pattern).

The surface dose contributed by the backscattered particles, expressed as a fraction of the dose contributed by the incident particles, is a figure of interest. By an analysis of relevant experimental data it can be shown (*8*) that, in the case of a tissue-like material such as Lucite, the fraction is about $\frac{1}{4}$ for all β-ray emitters of energy between 0.17 Mev (S^{35}) and 1.7 Mev (P^{32}) and for all angular distributions not emphasizing oblique incidence much more than the diffuse pattern.

Energy Spectrum

It is a very important physical fact in photographic β-ray dosimetry that the β-ray energy spectrum shape remains substantially constant, as the β-rays pass through an absorber, throughout a considerable fraction of the maximum range. Brownell has demonstrated this experimentally in the case of P^{32} (*4*). Furthermore, he has pointed out that the approximate constancy of spectral shape for other isotopes can be inferred from two features of their absorption, namely, constancy of angular distribution (after equilibrium is established) and the exponential shape of absorption curve. The special significance of an approximately constant spectral shape is that it often permits the elimination of errors that otherwise would result from the energy dependence of film sensitivity. For example, it is possible to calibrate a film with a standard source whose β-rays have undergone a particular degree of self-absorption, and to use this calibration with fairly good accuracy for the β-rays from a different source (of the same isotope) having different, or even unknown, absorption.

APPARATUS, TECHNIQUES

A description of experimental methods used in the investigation clarifies its usefulness and limitations.

Spectrograph

In studies of the dependence of film response on β-particle energy, the first experimental technique was to expose the film to a calibrated monokinetic β-particle flux. For this purpose, a 180-degree variable field magnetic

TABLE 1—Film Data and Processing

Film	*Emulsion* (mg/cm²)	*AgBr* (mg/cm²)	*Cellulose acetate film base* (mg/cm²)	*Development**	*Fixation†*
No Screen X-ray	5.8‡§	3.5‡	26	7.0 min, Kodak X-ray dev. (powder)	15 min, Kodak X-ray fixer
Indust. X-ray Type A	3.8‡§	1.8‡	21	7.0 min, Kodak X-ray dev. (powder)	10 min, Kodak X-ray fixer
NTB Stripping	4.5§	3.7	—	30 min, in D 19	7 min, Kodak acid fixer
Cine Positive No. 5302	2 1§	0.72	—	15 min, ¼ conc. D 19	6 min, Kodak acid fixer
SWR	0.17	0.16	—	4 min, ½ conc. D 19	3 min, Kodak acid fixer

* 20° C.
† Preceded by stop bath: 2.5% acetic acid, ½ min.
‡ Each side of film base.
§ Plus T coat—thin gelatin layer (0.1 mg/cm²) to protect emulsion surface from abrasion.

β-ray spectrograph was constructed for the range 0.03–1.8 Mev. The source was a 35-mc unit of Sr^{90}-Y^{90}. The resolution of the slit system was such that half the β-particles incident on the film were within an energy spread of less than 4%. The mean energy of the transmitted electrons was determined to an accuracy of 2–3% by measurements of magnetic field strength. Various rubber or Lucite film holders were arranged to give incidence at 0, 17.5, 35, 52.5, 70 deg.

The number of β-particles/cm^2 to which the film was subjected was determined by calibration of the flux with a proportional counter. From the measured number of particles per cm^2, the surface dose was calculated by means of the Bethe-Bloch formula for rate of energy loss (*9*). A correction was added for the additional dose contributed by the backscattered electrons.

When reference is made in this article to the dose to which a film was subjected, it is the dose that would have existed at the surface of a piece of Lucite (methyl methacrylate), had it been in the film's position. Lucite was chosen because it is a tissue-like material having an unambiguous chemical composition. This definition has been used in these calculations because the user is usually interested in the dose to which tissue would be subjected if it, instead of film, were being irradiated. The dose at the actual film surface, a quantity that is seldom of interest, would be somewhat different in view of the difference in composition between tissue and emulsion.

Under these assumptions, the backscatter correction amounts to an increment of 25% added to the dose contributed by the incident electrons. It is estimated that the dose was known absolutely to within 10–15% over most of the spectrum, and relatively to somewhat better accuracy.

Thin Plane Sources

Direct measurements have been made to examine the dependence of film sensitivity on the amount of absorption undergone by β-rays before reaching the film. The expected dependence is attributed to changes produced in both angular and energy distribution during the absorption process. These measurements also provided a second independent evaluation of the dependence of film sensitivity on β-ray energy over a wide energy range.

For these measurements, thin plane β-ray sources of four different isotopes were prepared by a technique that gave both fairly good uniformity over an area 2-in. in diameter and also a prescribed activity per unit area. The isotopes were S^{35} (0.17 Mev), W^{185} (0.43 Mev), Tl^{204} (0.78 Mev), and Y^{91} (1.54 Mev). In the preparation technique, a very insoluble compound of the active isotope was precipitated in the presence of a protective colloid such as gelatin. This fine suspension then was poured onto the surface of a flat Lucite disk that was made level by floating it in a pool of mercury. The thickness of the Tl source was 2.2 mg/cm^2; the other sources were less than 0.5 mg/cm^2. The uniformity of the Y source was better than 5%; that of the others was not as good, but in all measurements on the sources satisfactory averaging methods were available to eliminate troubles from small nonuniformities.

The sources were covered with several cellulose acetate absorbers, three or four per source, covering the range of about 0.1–1 half-thickness for the β-radiation from the particular isotope. The dose rate at the absorber surface was calibrated in an extrapolation chamber to an absolute accuracy of 2 or 3%. Exposures of film to the sources were timed to give the desired total dose at the film surface.

Standard Sources

A set of standard sources, called a "radiator," was prepared for use in tests on reproducibility of development, correction for small differences in processing between different development batches, and convenient plotting of density-exposure relationship to permit comparison of different exposures.

The radiator was prepared as follows: a solution of Sr^{90}-Y^{90} was diluted successively through six steps, each one decreasing in activity by a factor of 0.44. Each solution then was mixed with an accurately weighed amount of fine plaster of paris. The paste was poured into a mold consisting of a small brass block containing six holes of $\frac{1}{4}$-in. diameter and $\frac{1}{4}$-in. depth. The bottom of the mold was formed by a glass plate that was removed after the plaster hardened. This left a smooth flat surface on each source. The final calibration of relative source activities was performed with a counter; values were found within 2–3% of that expected from the solution activity ratios. The absolute activity of the sources (about 150 μc/gm, maximum) was sufficiently high that exposures of only a few minutes duration were adequate to cover the whole density range of interest. High-resolution quantitative autoradiograph measurements on numerous areas of only 0.001 mm^2 proved the uniformity of the central region of each disk. These radiators were of greatest value in their innumerable calibration applications. After 3 years they remain unchanged, except for the few per cent decrease in absolute activity.

This simple method of source preparation provides a reliable, homogeneous source of known activity per gram only under certain conditions. These conditions appear to be that the active ion in solution form an insoluble compound with either the Ca^{++} or SO_4^{--} ions in the plaster of paris. Active Ca^{++}, Sr^{++}, SO_4^{--}, and PO_4^{---} have all been found suitable for the method. However, Co^{++} is not, owing to redistribution of activity as excess water evaporates from the wet plaster. Water remains in the plaster only to the extent of an 18% increase of weight over that of dry powder. Surface activity of the sources will not be uniform on a scale smaller than powder grain size unless the β-ray range is much greater than grain size.

Films

Data on the films investigated and the conditions of processing are given in Table 1. All films are products of Eastman Kodak Co., Rochester, N. Y. All measurements on the SWR film were subject to considerable error because the absence of the protective "T coat" allowed extensive exposure through abrasion in handling.

Film Processing

A standardized development procedure was evolved that was found, in extensive tests with calibration exposures on Eastman Kodak Contrast Process Ortho, to be reproducible with a mean fluctuation of 2.5%. This procedure allowed constant agitation, and careful control of temperature and development time.

A further provision was made for standardizing development by placing calibration exposures from the radiator on the edge of each film strip. By intercomparison of these calibration ex-

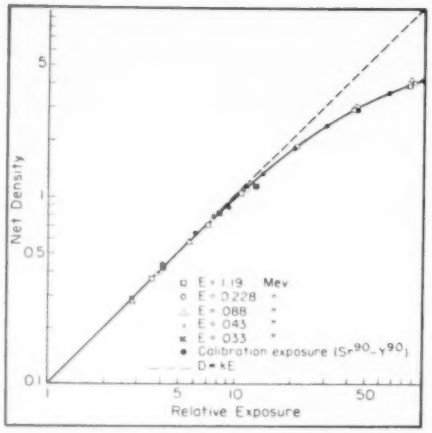

FIG. 3. Density-exposure relationship for single-emulsion Eastman No Screen film

posures it was possible to correct for slight fluctuations from batch to batch.

To determine the photographic response of only the front emulsion layer on a double-coated film, the rear layer was removed by soaking in 1N HCl for 15 min after processing the pair.

Densitometry was performed by reading diffuse density with an Ansco Color Densitometer. Accuracy, after calibration against a standard gray scale, is claimed by the manufacturers to be ± 0.02 units of density over the whole density range.

EXPERIMENTAL RESULTS

The unit of *exposure* should be chosen appropriate to the purpose of measurement. For dosimetry, the absolute unit of radiation dose, namely the erg/gm, is most convenient. In β-ray flux density measurements, the appropriate unit is β-particle/cm^2. *Sensitivity*, which can be defined in several ways, is defined here as the reciprocal of the exposure required to produce a net density (above fog) of 0.30. Since two different units of exposure have been given, we have two corresponding units of sensitivity. For dosage sensitivity, the unit is $(\text{erg/gm})^{-1}$; for particle number sensitivity, it is $(\beta\text{-particle/cm}^2)^{-1}$.

Density-Exposure

The relationship between density and exposure is usually shown as a density (D) vs. log exposure (E) plot. This is known as an "H and D" curve. In this section, attention is directed solely at curve *shape* and its dependence on β-ray energy. Therefore, exposure is shown only in arbitrary units, so that curves at different energies can be superimposed for more convenient comparison of shape. In the next section, consideration is given to the dependence of density on absolute exposure (film sensitivity).

The experimental density-exposure relationship found at several different energies for single-emulsion Eastman No Screen is shown in Fig. 3. In this graph, D as well as E is plotted on a log scale. Such a graph has an advantage over the H and D curve (and also the D vs. E type of plot) in that it permits presentation of experimental data with good accuracy over the whole density range. With these coordinates, the relationship $D = kE^n$ would appear as a straight line having slope = n. The special case with $n = 1$ is shown by the dashed line.

Two significant features stand out. First, and most important, is the conclusion that the curve shape is independent of energy, in the density and energy ranges shown, within limits of a few per cent. It is interesting that this is true for particles of energy even as low as 0.033 Mev, since the 2 mg/cm^2 maximum range of these electrons is only one-third the emulsion thickness. However, had the 0.033 Mev exposure been carried to a density greater than 1, this curve would have begun to fall below the higher energy curves. The asymptotic value approached after long exposure would have been lower because maximum D is proportional to effective emulsion thickness.

The same independence of curve shape from energy over this wide range of energies and densities was exhibited by all other films (except SWR, which was not investigated). This is true even for such films as double-emulsion No Screen, where β-rays of less than about 0.2 Mev fail to reach the second emulsion at all, and Cine Positive, for which the deviation of n from unity suggests difficulties mentioned in the following paragraphs.

For X- and γ-ray exposures, the density-exposure curve shape would be identical with the shape found in β-ray exposures. It would be even less dependent on photon energy than on β-ray energy, since absorption of the penetrating photons would play a negligible role.

The significance of this practical independence of density-exposure curve shape from β-ray energy is great. For example, a calibration curve produced by β-rays from a particular source (e.g., Sr^{90}-Y^{90} radiator) permits determination of the relative magnitude of two successive exposures of any other source without knowledge of its β-ray energy.

The second significant feature of Fig. 3 is that D is very accurately proportional to E (n is very nearly unity) as high as $D = 1$. It can be shown that if every grain requires a unique number of hits n, and if all grains are of the same size, the initial density vs. exposure curve has the shape $D = kE^n$. By this analysis, No Screen grains are

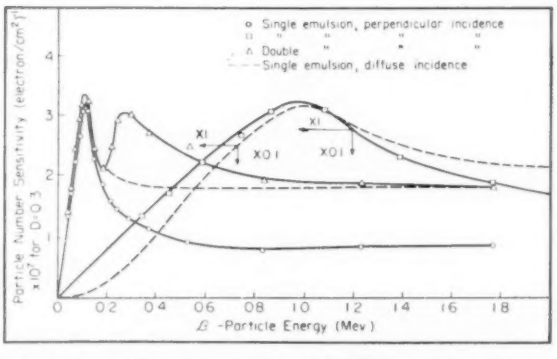

FIG. 4. Particle number sensitivity of Eastman No Screen film

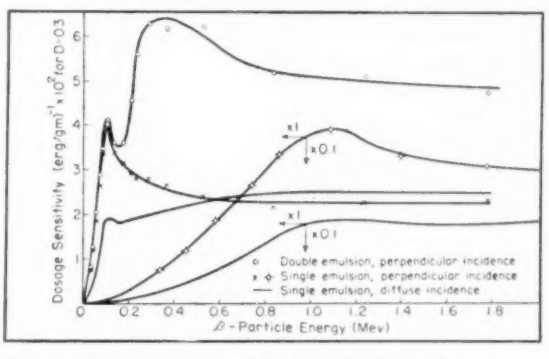

FIG. 5. Dosage sensitivity of Eastman No Screen film

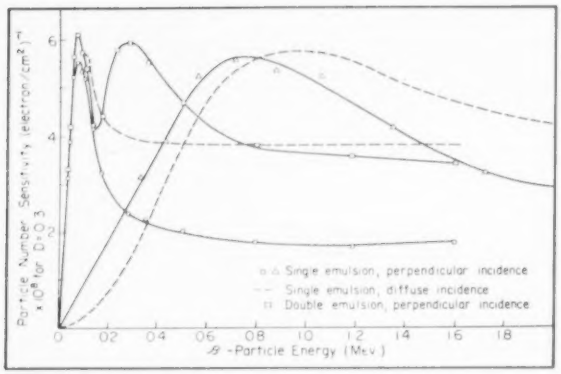
Particle Number Sensitivity (electron/cm²)⁻¹ x10⁸ for D=0.3
Single emulsion, perpendicular incidence
Single emulsion, diffuse incidence
Double emulsion, perpendicular incidence
β-Particle Energy (Mev.)

FIG. 6. Particle number sensitivity of Eastman Type A film

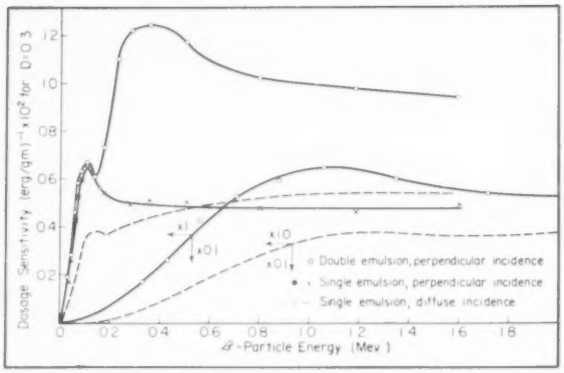

FIG. 7. Dosage sensitivity of Eastman Type A film

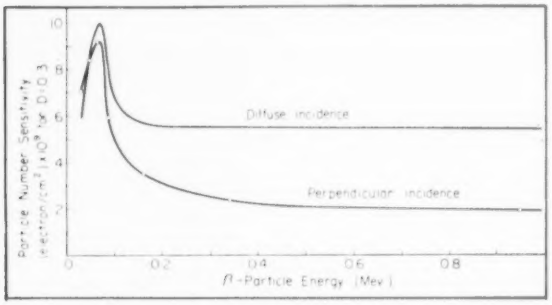

FIG. 8. Particle number sensitivity of Cine Positive No. 5302 film

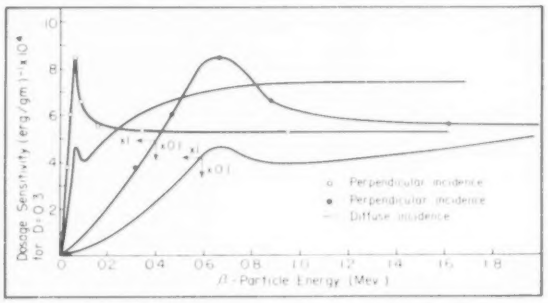

FIG. 9. Dosage sensitivity of Cine Positive No. 5302 film. Diffuse data accuracy low above about 0.3 Mev

seen to be exposed in single-hit events. For Type A, it was found that $n = 1.2$; for Cine Positive, $n = 1.2$; and for NTB, $n = 1.1$. Failures in the assumptions cause the equating of average number of hits per grain with the value of n to be less valid if n is greater than unity. In this case it is safe only to assume that the average number of hits per grain is not less than n.

When more than one hit per grain is required for development, one might expect fewer hits to be necessary for the case of high specific ionization particles than for low. This situation would give rise to the complication of dependence of density-exposure curve shape on β-ray energy. However, within the experimental error of a few per cent, no such dependence was observed on these films down to 0.07 Mev, the lowest energy tested.

The detailed shape of the curve in Fig. 3 is not especially significant. It would depend very much on processing conditions.

Sensitivity

The degree to which angle of incidence and β-ray energy affect sensitivity largely determines the usefulness of a film for dosimetry.

Perpendicular incidence. The sensitivities of all five films for perpendicularly incident β-particles and of three of the films for diffusely incident particles are shown in Figs. 4–13. In this section attention is directed toward the curves for perpendicular incidence.

Particle-number sensitivity data are considered first. For all films, these curves consist of three distinctly recognizable parts. The first segment is the almost linear rise of sensitivity with energy, which is to be correlated with the increasing depth of penetration of the electrons into the emulsion as their energy increases.

The second segment of the sensitivity curve is the rather abrupt drop of sensitivity beyond the peak. This drop can be attributed in part to decreasing track length of the β-rays within the emulsion as their energy increases, a result of decreasing scattering. A second reason, of approximately equal importance, is the decrease in specific ionization of the β-rays as their energy increases.

The third segment of the curve is the flat region above 0.5 or 0.6 Mev. Increase in path length through scattering is negligible and specific ionization is at its nearly-flat minimum.

SWR, which differs significantly from this description of the typical film, gives insight into the role played by thickness of emulsion. Other measurements showed that the dependence of grain sensitivity on specific ionization was the same for SWR as for all other films, except NTB.

Dosage sensitivity curves were then computed from the particle-number sensitivity curves by the Bethe-Bloch formula together with backscatter corrections, as described previously.

All curves involved the development conditions specified previously. It is well known that sensitivity increases with increasing development time. To study this effect in the case of the particular Eastman No Screen (single emulsion) film, four film strips were given identical exposures in the spectrograph, at several different energies, and were developed for 1.75, 3.50, 7.0, and 14.0 min, respectively. The results are shown in Fig. 14.

Sensitivity increases monotonically with development time. The increase is somewhat less rapid for low energy electrons than for high.

Nonperpendicular incidence. In most experiments the β-rays are not incident perpendicularly on the film;

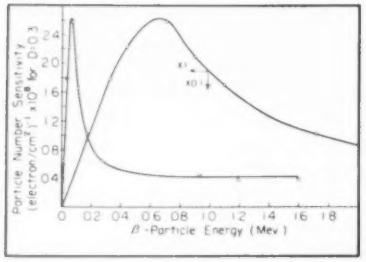

FIG. 10. Particle number sensitivity of NTB Stripping film. Perpendicular incidence

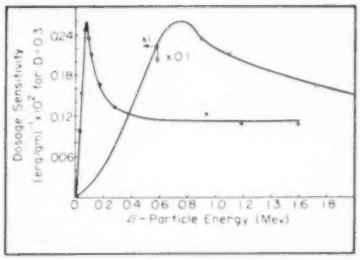

FIG. 11. Dosage sensitivity of NTB Stripping film. Perpendicular incidence

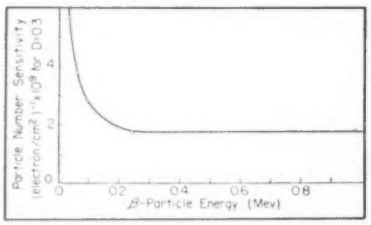

FIG. 12. Particle number sensitivity of SWR film. Perpendicular incidence

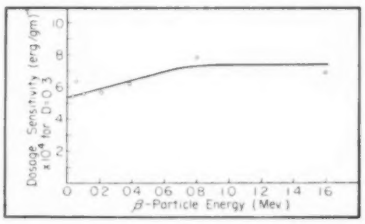

FIG. 13. Dosage sensitivity of SWR film. Perpendicular incidence

therefore, it is important to consider the effect of angle of incidence on sensitivity. On three films, No Screen (single emulsion), Type A (single emulsion), and Cine Positive, spectrograph exposures were made at the angles of incidence 0, 17.5, 35, 52.5, and 70 degrees. The results are shown, in the case of No Screen, in Fig. 15. Curves are not accurate for large angles at high energies because of experimental difficulties.

The results are to be compared with the ideal response, which would consist of a single horizontal line at unity. The departure from ideal is caused by scattering and absorption within the emulsion. At high energies, where these effects are very small, the angle-of-incidence dependence of sensitivity is correspondingly small. At low energies, the dependence is serious. These curves, together with corresponding data on the thinner emulsions of Type A and Cine Positive, emphasize the importance of emulsion thinness if film dosage sensitivity is to be nearly independent of angle of incidence.

Curves for particle number sensitivity as a function of angle of incidence can be calculated from the dosage sensitivity data by multiplication of each curve by sec θ. This type of sensitivity is most nearly independent of angle of incidence at low energies, where β-ray track length in the emulsion is substantially the same for all angles of incidence. For No Screen, response is quite good below 0.2 Mev. For particle number measurements, thick emulsions are less dependent on angle of incidence than are thin emulsions.

Data for diffuse incidence sensitivity may be calculated from the curves for the discrete angles of incidence, through weighting each curve by $dP(\theta)/d\theta$ for diffuse incidence. The results for both particle number and dosage sensitivities are included in Figs. 4–9. The accuracy is low above 0.5 Mev, as in the case of the original angle of incidence data. At energies this high, dosage sensitivity for diffuse incidence must be very nearly equal to that for perpendicular incidence.

Unfortunately, it was not possible to make the angle of incidence studies for NTB and SWR. However, for NTB the diffuse incidence sensitivity can be estimated from the perpendicular incidence data on NTB and the angular distribution data on the other films. When this is done, it is found that on NTB the dosage sensitivity for diffuse incidence, as a function of energy, more nearly approaches the ideal of a horizontal straight line than for any of the other films.

Relative energy dissipation. From the perpendicular incidence data, it is possible to determine the energy dissipation required at 1 Mev, relative to that at 0.04 Mev, to render a grain developable. The energy dissipation in the emulsion by a 1-Mev particle can be computed from the Bethe-Bloch formula with the emulsion thickness and backscatter data already given. The dissipation by a 0.04-Mev particle is its full energy, minus a correction of about 10% for backscatter. These calculations, combined with the sensitivity measurements, lead to the relative energy dissipation per grain as shown in Table 2. In the ideal film, the ratio should be unity.

Continuous Spectrum

Exposures were made with the continuous spectrum thin sources for two reasons. First, the effect of absorption of the β-rays on their "exposing

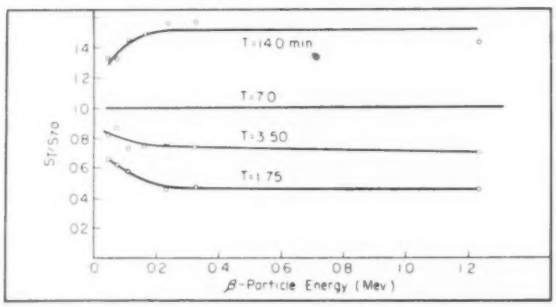

FIG. 14. Sensitivity of single-emulsion Eastman No Screen film for development time T relative to sensitivity for T = 7.0 min

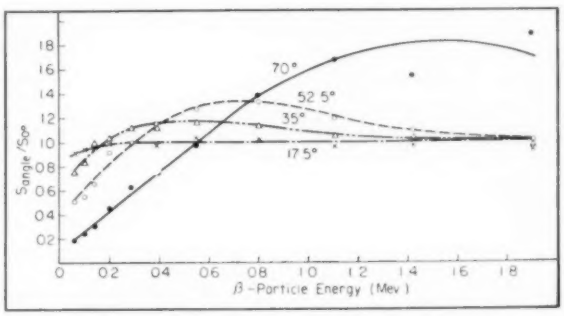

FIG. 15. Dosage sensitivity of single-emulsion Eastman No Screen film for various angles of incidence relative to 0 deg incidence

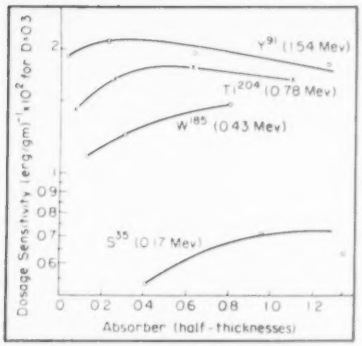

FIG. 16. Dosage sensitivity of single-emulsion Eastman No Screen film with various absorber thicknesses over thin plane surfaces of several isotopes

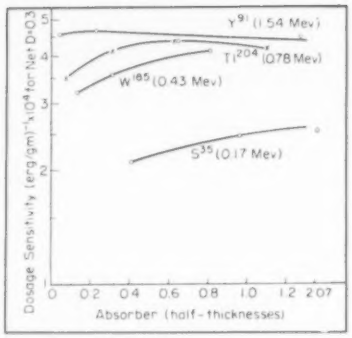

FIG. 17. Dosage sensitivity of Cine Positive No. 5302 film with various absorber thicknesses over thin plane source of several isotopes

efficiency" was investigated. Second, the energy dependence of the film was observed under the practical conditions of β-ray dosimetry, thereby checking the monokinetic data.

The most extensive measurements were made on No Screen and Cine Positive films. The results are shown in Figs. 16 and 17. To compress all the data onto a single graph, the amount of absorber in each case is specified in terms of half-thicknesses. The half-thickness values substituted in the computations for each isotope are the following: Y^{91}, 76 mg/cm²; Tl^{204}, 29 mg/cm²; W^{185}, 12.2 mg/cm²; and S^{35}, 3.1 mg/cm².

The ideal response would be a single horizontal line for all isotopes. The most marked deviation from the ideal is in the decrease of sensitivity with decreasing isotope energy, a condition expected on the basis of the monokinetic, diffuse incidence, dosage sensitivity curves. However, the dependence of sensitivity on amount of absorption is not nearly as severe a failure. In this regard, a rather abrupt initial rise in sensitivity occurs with absorption. This is attributable chiefly to rapid changes in the angular distribution from sin θ at the surface of the thin source toward diffuse at the surface of the absorbers. This initial rise would have been more apparent in the data had it been possible to extend the measurements to smaller absorber thicknesses. At zero thickness, when surface dose rate is nominally infinite, sensitivity would be zero.

Following the initial rise, only slow changes occur in the sensitivity, due to slight changes in both the angular distribution pattern and the energy spectrum. That the flat sensitivity vs. absorber thickness relationship extends through a large absorber range has been shown for special cases (*1*, *2*). Using isotopes of energy greater than 1 Mev, from thick sources, it was found that the dosage sensitivity of several films drops by only about 10–20% after sufficient absorption to reduce initial dosage rate by a factor of 100.

In each case, the other three films were exposed to the four sources through only the thinnest absorber. Because of rapid changes in angular distribution with absorber thickness in this range of thickness, these four values of sensitivity are not uniquely characteristic of the four isotopes. A better value for intercomparison would be the peak sensitivity that occurs at a somewhat greater absorber thickness. The ratio of peak sensitivity to sensitivity at minimum absorber thickness probably depends largely on emulsion thickness, at least insofar as the difference is caused by changes in angular distribution. Since the emulsion thicknesses of Type A and NTB are intermediate between those of the No Screen and Cine Positive, a rough estimate of the peak sensitivities of these films for each of the four isotopes can be obtained from the more extensive data on No Screen and Cine Positive. The measured sensitivity at minimum absorber thickness, and the estimated peak sensitivity for each isotope, are shown in Table 3. NTB is seen to be the least energy dependent.

In applying these thin-source dosage sensitivity data, estimates of reproducibility should be kept in mind. The variation of sensitivity (for a particular isotope) with absorber thickness, largely a property of the β-ray spectrum, will be roughly the same even between different types of film under different development conditions. The variation of sensitivity with β-ray energy, a property of emulsion thickness, grain size, etc., will be somewhat different for different types of film, but should be rather constant between different development batches of the same type of film. The absolute sensitivity, a property of development conditions as well as of emulsion characteristics and β-ray energy, will not be very reproducible even between development runs on the same type of film.

Comparison

Brownell's spectrograph measurements on P^{32} permit a good estimate of the angular distribution (diffuse) and energy spectrum of the β-rays emitted from the Y^{91} source covered

TABLE 2 Energy Dissipation

Film	*Relative diss./grain (at 1 Mev/at 0.0½ Mev)*
No Screen	0.56
Type A	0.43
Cine Positive	0.58
NTB	0.95

TABLE 3 Energy-Dependence of Film Sensitivity

β-ray maximum energy (Mev)	*Sensitivity ([erg/gm]⁻¹ × 10⁴)*				
	Type A		*NTB*		*SWR*
	Min. absorp.	*Peak*	*Min. absorp.*	*Peak*	*Min. absorp.*
0.17 (S^{35})	11.6	14.8	6.0	7.7	2.4
0.43 (W^{185})	25	32	8.8	11.4	4.3
0.78 (Tl^{204})	26	33	9.0	11.2	4.8
1.54 (Y^{91})	39	41	11.1	11.7	7.0

by an absorber of one half-thickness. Graphical integration of the diffuse incidence monokinetic sensitivity data over the energy spectrum yields a value for the expected sensitivity of the films to the Y^{91} source covered by one half-thickness of absorber. These calculations then can be compared with the direct measurements.

In the case of No Screen, the computed sensitivity was 7% high; in the case of Cine Positive, it was 33% high. The rather large discrepancy in the case of Cine Positive is undoubtedly a result of experimental errors in the high-energy monokinetic angle of incidence measurements, which were especially unreliable for this thin emulsion. The close agreement in the case of No Screen, however, gives confidence in the monokinetic data.

All measurements have demonstrated the high potentiality of NTB as an accurate β-ray dosimeter. Limitations are set by absorption and scattering within the emulsion, low sensitivity, and perhaps lower reproducibility than the other films. An automatic grain counter recently has been developed that would extend greatly the effective sensitivity of NTB (*10*).

Dosimetry Applications

Because of the departures of film response from the ideal for dosimetry (or for any other type of β-detection), reliance must be placed on calibration for accurate results. The establishment of the relative density-exposure relationship (e.g., with a Sr^{90}-Y^{90} radiator) has been shown to be a simple and reliable matter. In many applications involving only relative measurement, such as multiple exposures of the same or similar sources, this calibration is sufficient and can provide accuracy to a few per cent. When absolute measurements are required, precautions for reliable calibration of sensitivity become more elaborate. The problems involved may be summarized in the light of experimental findings.

Sources whose surface dose rates are to be measured fall into one of three classes: both spatial distribution and isotope known, isotope known but spatial distribution unknown, or, neither spatial distribution nor isotope known.

The first class, which is the simplest, might be represented by a β-ray applicator whose dose rate is to be measured under conditions of higher spatial resolution than possible with other conveniently available instruments. For this case, it may be possible to prepare a standard source that duplicates the experimental source with regard to both isotope and degree of absorption, yet is large enough to permit calibration with some absolute instrument. Absolute photographic dosimetry under these conditions can be accurate to a few per cent.

The second class, probably the most common, may be represented by inhomogeneous distributions of Ca^{45} in bone or I^{131} in thyroid. The most satisfactory calibration source in this case is usually an "infinitely thick" homogeneous source of identical isotope and similar atomic constitution as the specimen to be studied. Its surface dose rate may be either measured directly with an absolute instrument or calculated from a knowledge of the absolute activity per gram and the average β-ray energy.

Question arises on the error caused by differences between spatial distribution of activity in the specimen and the homogeneous distribution in the calibration source. If the unknown distribution is homogeneous over distances equal to a few half-thicknesses, errors will be negligible. If the unknown distribution is a thin plane, errors would be small (depending on isotope and film) if the distance between plane and film were at least an appreciable fraction of one half-thickness. If the unknown distribution consists of a point, errors will not be large for β-rays of energy greater than a few-tenths Mev because sensitivity for diffuse and perpendicular incidence is nearly the same.

The third class, source distribution and isotope both unknown, is susceptible to greatest error. However, if an emulsion such as NTB (having a sensitivity substantially independent of energy for diffuse incidence) could be employed, errors would not be much greater than for the second class.

SUMMARY

For most practical conditions, the relationship between density and relative exposure is independent of β-ray energy.

Dosage sensitivity for perpendicularly incident electrons is a strong function of energy at low energies. Sensitivity starts at zero for zero energy, rises to a peak at roughly 0.1 Mev, and thereafter decreases to a plateau of about $\frac{1}{3}$ to $\frac{2}{3}$ maximum sensitivity for energies greater than approximately 0.5 Mev.

Dosage sensitivity is a rather strong function of the angle of incidence of the electrons, especially at low energies and large angles of incidence. For the special case of diffuse incidence, which is approximated in exposures to thick sources in contact with the emulsion, dosage sensitivity increases monotonically with energy, reaching a flat maximum at about 1 Mev. The initial rise between 0 and 0.1 Mev is rapid, reaching perhaps $\frac{2}{3}$ the maximum. This is followed by a gradual increase up to the flat maximum.

For continuous spectrum β-rays, absorption of the β-rays by sheets of matter placed between source and film has relatively little effect on their exposing efficiency, particularly at high energies. This is very useful in the accurate calibration of β-ray exposures for dosimetry measurements, and is the most important practical conclusion from this investigation.

Dosage sensitivity of NTB for diffusely incident electrons is least dependent on electron energy. If a thinner emulsion were employed, together with more sensitive density measurement techniques, NTB would be a very powerful dosimetry instrument.

Over-all reproducibility of β-ray film measurements is good to a few per cent when calibration with standard sources is carried out.

* * *

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BIBLIOGRAPHY

1. E. S. Jetter, H. Blatz, NUCLEONICS **10,** No. 10, 43 (1952)
2. E. Tochilin, R. Golden, NUCLEONICS **11,** No. 8, 26 (1953)
3. R. A. Dudley, B. M. Dobyns, *Science* **109,** 327 (1949)
4. G. L. Brownell, NUCLEONICS **10,** No. 6, 30 (1952)
5. S. Eklund, *Arkiv Mat.* **33A,** No. 14, 50 (1945)
6. B. P. Burtt, NUCLEONICS **5,** No. 2, 28 (1949)
7. H. V. Neher, *Phys. Rev.* **37,** 655L (1931)
8. R. A. Dudley, Thesis (Massachusetts Institute of Technology, Physics Department, Cambridge, Mass., 1951)
9. E. G. Segre, "Experimental Nuclear Physics" (John Wiley & Sons, Inc., New York, 1952)
10. R. A. Dudley, S. R. Pelc, *Nature* **172,** 992 (1953)

Determining Mesothorium

Useful in thorium processing, a simple technique is described for analyzing mesothorium contamination. Extraction of actinium-228, the short-lived daughter of mesothorium, provides a much more rapid analysis than a direct determination

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THE COMPLEX DECAY CHAIN of thorium makes analysis for mesothorium (Ra^{228}) difficult.

Since Ra^{228} is a beta emitter, analysis by beta counting would appear feasible. However, its beta ray has a very low energy, 0.053 Mev, making it nearly impossible to measure. The growth of its daughter, 6.1-hr Ac^{228} ($MsTh_2$), would also complicate the analysis since it has a 1.55-Mev beta. The obvious answer, to let the daughter grow to equilibrium before making the measurement on the sample, is of no value since the other radium isotope in the chain, Ra^{224} (ThX), also gives rise to beta emitters that grow into the sample in about the same length of time. These are 10.6-hr Pb^{212} (ThB), followed by 60.5-min Bi^{212} (ThC) and 3.1-min Tl^{208} (ThC″).

The two radium isotopes are present in thorium in very different amounts at various times after the preparation of pure thorium sample. The growth of Ra^{228}, the first member of the chain, obeys the relationship $(1 - e^{-\lambda t})$ in which λ is 0.693/6.7 or 0.103 yr^{-1}. The regrowth of Ra^{224} after a separation is much more rapid, of course, since in this case λ is 69.3 yr^{-1}. However, once Ra^{224} reaches equilibrium it follows the behavior of its parent, 1.9-yr Th^{228} (RdTh). Because the chain has been broken by removal of Ra^{228}, the Th^{228} and Ra^{224} decrease in abundance with time for about 5 yr, at which time they are present to about 0.4 of their maximum abundance. They then gradually increase and are back near equilibrium in 20 yr. Thus, a month after separation, the Ra^{224} content would be near the value that it had before the separation while the Ra^{228} content would be less than a per cent of its preseparation value. On the other hand, in thorium that has stood for about 6 yr, both radium isotopes would be near half their maximum concentration.

An analysis for total radium isotopes would have little meaning as far as the Ra^{228} content is concerned. A distinction between the two radium isotopes must be made to determine the Ra^{228}. By reason of its shorter half-life, Ra^{224} is not a health hazard except at much higher concentrations than those for Ra^{228}. It is obviously of little value as an industrial source of alpha radiation. Its short life also means that it will decay out of a separated radium sample containing both isotopes so that the activity 3 to 4 weeks after the separation would be a measure of the Ra^{228} only. However, a delay of 3 weeks between the time of doing the analysis and obtaining the answer is certainly not desirable.

Actinium-228 is the only isotope of any rare earth-like element in the decay chain. Also, within two days after a separation, the radioactivity due to Ac^{228} is equal to that of Ra^{228} and continues this way until another separation is made. Consequently, a determination of this unique isotope, Ac^{228}, can be used to measure the Ra^{228} content. The half-life is long enough to permit a fairly thorough separation and sufficiently different from other members of the chain that the purity of the precipitate can be checked by following the decay. Back extrapolation of this decay curve to the time of separation gives a number that measures the Ra^{228} content.

Experimental

The method used for the determination of Ra^{228} in thorium samples is based on the separation of thorium and its radioactive decay products by ex-

Content of Thorium Nitrate

Why Analyze for Mesothorium?

In connection with the processing of thorium for use in atomic energy or other applications, the behavior of the natural impurities in thorium, its daughter products, becomes of interest. The longest lived member of the chain of decay products is 6.7-yr Ra^{228} ($MsTh_1$). It is the only non-thorium member of the chain with a half-life of more than a week.

Under certain circumstances, Ra^{228} may constitute a health hazard. An estimate of its toxicity, based on its chemical nature and half-life and the half-lives and energies of its alpha-emitting daughter products, shows it to be about as toxic as radium (Ra^{226}) if equal activities of the two are compared. Since its half-life is shorter than that of radium by a factor of 240, on a weight basis it is roughly 240 times as toxic as radium, making it one of the most toxic substances known. Fortunately this short half-life also establishes that its abundance is very small. At equilibrium, 0.47 μg or 100 μc of Ra^{228} are present in each kilogram of thorium.

The decay and growth relationships in the thorium series are quite complicated (1). However, the amount of Ra^{228}, the first daughter product, follows the simple growth equation. The rate of growth in a freshly separated sample is close to 0.2% of the maximum each week.

The separation of the Ra^{228} from a fairly old thorium sample and its collection and concentration in a small amount of material in chemical or metallurgical processing could create a health hazard. On the other hand, the amount of Ra^{228} in a freshly separated sample would be so much smaller that the same operation could be done without hazard.

Consequently, it may be important either to know the history of the thorium being processed or to be able to analyze for its Ra^{228} content. Since this history includes the types of processes through which the thorium has been carried and the behavior of the Ra^{228} through these processes, it is not always determinable. An analytical method for Ra^{228} becomes the only answer in such a situation.

traction with thenoyltrifluoroacetone in benzene (2).

In the presence of lanthanum and lead carriers, the thorium is removed by extraction at *p*H 2. The lanthanum, actinium and lead are removed by extraction at *p*H 6. Lead is removed by precipitating it as the sulfide. Lanthanum and actinium are then precipitated as oxalates, filtered and counted.

Reagents. The reagents used and their concentrations are:

Thenoyltrifluoroacetone, TTA (Dow Chemical Co.), 0.25*M* in benzene
Ammonium hydroxide, 1 to 1
Sodium hydroxide, 1.0*N*
Nitric acid, 0.1*N*
Oxalic acid, 10 mg/ml
Lead nitrate, 10 mg of lead/ml
Lanthanum nitrate, 10 mg lanthanum/ml, 5.86 gm La_2O_3 and 10 ml concentrated HNO_3, diluted to 500 ml
Fluoborate solution, 10 mg/ml, 1.9 gm of NaF and 0.71 gm of boric acid diluted to 100 ml
Bromocresol green-chlorophenol red mixed indicator (3)

Apparatus. The radioactivity measurements were made with a Nuclear Instrument and Chemical Corporation model 161 scaling unit and a Tracerlab type TGC-1 G-M tube with a 2.2-mg/cm² window.

Procedure. The sample should contain no more than 0.85 gm of thorium. Thorium nitrate can be dissolved in water, but thorium metal or thorium oxide should be dissolved in nitric acid plus about 5 drops of solution containing 10 mg/ml of fluoborate ion. The solution is diluted to 40 ml; 0.5 ml of lanthanum nitrate solution and 1 ml of lead nitrate solution are added as carriers.

The *p*H of the solution is raised with sodium hydroxide until thorium hydroxide just begins to precipitate. The thorium is extracted by shaking in a separatory funnel for 15 min with three successive 50-ml portions of TTA in benzene. The aqueous layer now contains the daughter products free of thorium.

If zinc is present in the sample, it should be removed at this point by means of a mercury cathode. The apparatus described by Melavan (4) is satisfactory. A current of 0.2 to 0.3 amperes for 45 min is sufficient to remove up to 0.100 gm of zinc.

The aqueous solution is adjusted to

Results of Ra^{228} Analysis of Thorium Nitrate

Experiment	*Activity (cpm/gm Th)—individual determinations*	*Average*	*Standard deviation (%)*
Standard extraction method	1,726, 1,870, 1,905, 1,965 1,988, 2,035, 2,048	1,969	3.3
LaF_3 precipitation	2,035		
BF_4^- complex ion method	1,881, 2,012, 2,025, 2,048	1,992	3.3
Zn^{++} electrolytic method	2,025, 2,080, 2,116	2,074	1.8
Equilibrium thorium by standard extraction method	9,906, 10,081, 10,354	10,110	1.8

the color change of bromocresol green-chlorophenol red indicator (pH 6.1). The actinium, lanthanum, and lead are then extracted by shaking for 15 min with 50 ml of TTA solution. The pH is readjusted to pH 6 every 5 min during the extraction. A second extraction is made with 50 ml of fresh TTA, and the two portions of TTA are combined. The time of the final extraction is noted and taken as the zero time in the extrapolation of the counting rate. The activity is stripped from the TTA solution by two successive extractions with 50 ml of 0.1N nitric acid.

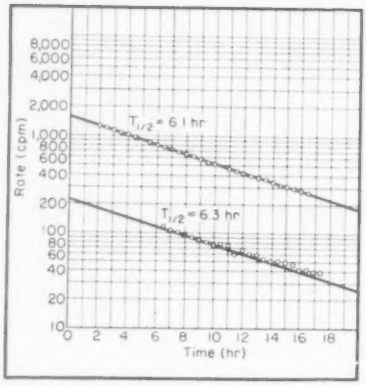
The 0.1N nitric acid solution, containing lanthanum, actinium, and lead, is freed of benzene by boiling and then cooled before precipitating lead sulfide by bubbling H_2S through the solution. The lead sulfide is separated by centrifuging; the excess hydrogen sulfide is removed from the centrifugate by boiling. Lanthanum and actinium oxalate are precipitated by adding 5 ml of oxalic acid solution and adjusting to pH 5 with dilute ammonium hydroxide. The precipitate is collected by filtering the solution through a filter stick. After drying at 110° C, the activity of the precipitate is measured by counting with the G-M counter. The activity of the sample is observed for 12 hr or more and the counting rate plotted against time. The purity of the precipitate is checked by observing the half-life; the decay curve is extrapolated back to the separation time to determine the amount of Ra^{228} in the samples.

Discussion

The reproducibility and accuracy of the method were checked by running a number of analyses of a selected sample of fairly old thorium nitrate, which was taken as a standard (see table).

The steady increase in the counting rate as the series progressed (see table) is quite good evidence that the technique was steadily being improved. The first measurement is sufficiently out of line with the others to be beyond the plausible limits of statistical fluctuations. Consequently, the average and standard deviation represent all values but the first. Averaging the reliable values from the various experiments using this solution gives a value of 2,000 ± 72. A weighting process eliminating some of the early low values gives 2,034 ± 40 as the average.

In almost all cases the decay curve



DECAY of actinium-228 samples

of the actinium sample showed only the 6-hr period of the Ac^{228}, indicating that the samples were quite pure. If there was a slight amount of longer-lived material present, it showed up as a low-intensity tail to the decay curve (see graph). After subtracting this component, these decay curves had only the 6-hr component present. The principal uncertainty in the method is the completeness of recovery of the actinium. Since it is not isotopic with the carrier used, the customary procedure for determining a chemical yield and correcting the removed activity to 100% chemical yield did not appear to be valid.

Actinium recovery. The completeness of recovery of actinium was checked by extracting the thorium from a sample, coprecipitating both radium isotopes with lanthanum fluoride, and counting this sample after the Ra^{224} and its daughters had decayed out. This value (see table) checked very well with the results obtained by the actinium separation procedure.

Another check on this completeness is the agreement between different analyses on the same sample. This agreement is sufficiently close to indicate that accidental losses of actinium are small.

A third check was obtained by the analysis of some equilibrium thorium nitrate. This material was Kahlbaum reagent thorium nitrate which is known to have been in the chemistry department for at least 35 yr. The Ra^{228} content would thus be at least 97% of its equilibrium value. The analysis of this material by this procedure gave an average counting rate of 10,110 ± 180 cpm per gram of thorium. The geometry of this position for the counter (second shelf), using a similarly mounted sample of standard P^{32}, was found to be 3.8 ± 0.3%. The use of P^{32} for geometry determination should be valid in this case since the P^{32} and the Ac^{228} β-rays have similar energies, 1.71 and 1.55 Mev, respectively.

With this geometry factor, 0.038 ± .003, the disintegration rate of these samples becomes (2.66 ± 0.21) × 10^5 dpm/gm Th. The calculated disintegration rate of Ra^{228} in equilibrium with thorium is 2.46 × 10^5 dpm/gm Th.

Thorium dissolution. The complete dissolution of thorium metal and thorium oxide is extremely difficult unless a trace of fluoride ion is present as a catalyst. However, the concentration of fluoride ion must be very low to avoid precipitation of lanthanum fluoride and loss of some of the actinium.

The hydrolysis of fluoborate ion was found to furnish sufficient fluoride ion to catalyze the dissolution of thorium samples and yet did not cause the precipitation of lanthanum. The results given in the table show that addition of up to 2.5 mg of fluoborate ion did not affect the results of the Ra^{228} analysis.

Removal of zinc. Interference of zinc with the analytical method results from the precipitation of zinc hydroxide when the pH of the solution is raised. Complexing the zinc with sodium salt of ethylenediaminetetraacetic acid was unsatisfactory since this reagent also complexed lanthanum and prevented its extraction. Zinc was selectively complexed by 1,10-phenanthroline, but this reagent was extracted by the benzene permitting the zinc to precipitate.

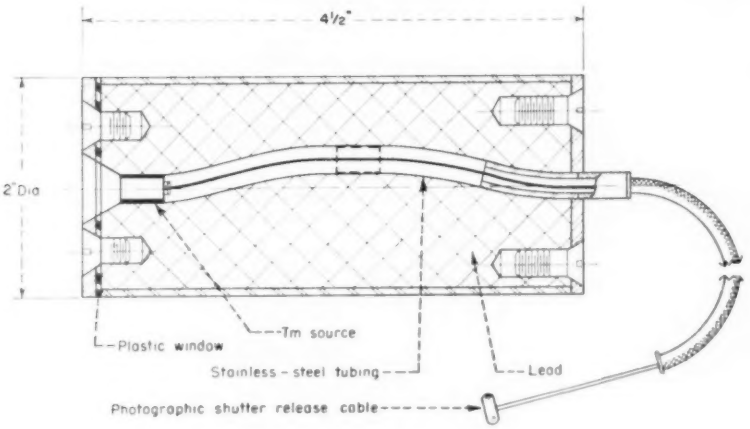
Removing the zinc by use of a mercury cathode was very satisfactory. Extraction of the thorium before using the mercury cathode improved the operation of the mercury cathode. Samples containing more than 0.1 gm of zinc were dissolved in hydrochloric acid since nitrate ion hindered the removal of larger amounts of zinc.

BIBLIOGRAPHY

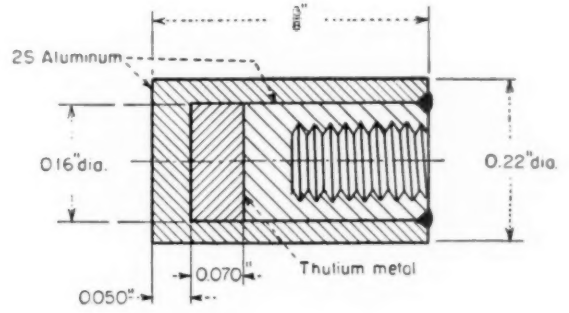
1. J. Fresco, E. Jetter, J. Harley. Radiometric properties of the thorium series, NUCLEONICS **10,** No. 8, 60 (1952)
2. F. Hagemann. The isolation of actinium, *J. Am. Chem. Soc.* **172,** 768 (1950)
3. N. Lange, ed., "Handbook of Chemistry," 8th ed. p. 944 (Handbook Publisher, Inc., Sandusky 1952)
4. A. D. Melavan. Electrolytic cell for use with the mercury cathode, *Ind. Eng. Chem. Anal. Ed.* **2** 180 (1930)

Portable Thulium Xray Unit

The three sections of this article consider the unit, methods for preparing thulium oxide or metal, and clinical radiography with a thulium-170 source



1 PORTABLE X-RAY UNIT, weighing less than 7 lb, is cylindrical shield with offset source tube. Cable release controls position of . . .



2 RADIOACTIVE THULIUM SOURCE contained in aluminum capsule that is welded shut. Source was irradiated in MTR reactor, provides (next page) . . .

I. The Portable Unit

By S. UNTERMYER
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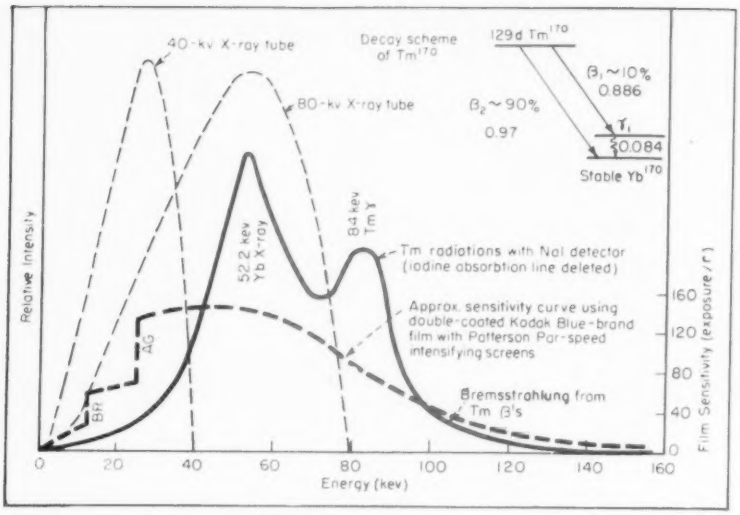
Lemont, Illinois

TITLE LETTERING for this article is a radiograph made using a thulium-170 source. The lettering was fabricated from solder and radiographed through the thickness of a copy of NUCLEONICS. This unorthodox application constitutes a graphic demonstration of thulium radiography.

For some time there has been a demand for simple, portable radiographic equipment for both medical and industrial use. Such equipment is of greatest value in isolated locations, where conventional bulky X-ray equipment is not available. Army field hospitals, small naval vessels, and isolated construction camps illustrate the areas where these units will probably have their first application. During the past 18 months, the Argonne National Laboratory has cooperated with the Army Medical Research Laboratory at Fort Knox, Ky., in the development of a simple, cheap portable X-ray unit using thulium radiations.

It is well to dispel the notion that such equipment might supersede conventional X-ray tubes. Standard X-ray equipment has been developed over many years to the point where superlative results can be obtained



3 **RADIATION ENERGY SPECTRUM that is comparable to that of 80-kv X-ray tube and matches sensitivity peak of film. Intensity is lower than that of X-ray tube, but usefulness of thulium unit is shown by . . .**

by experienced technicians. It seems most unlikely that these results can ever be matched by thulium sources, since X-ray tubes provide far greater intensity and permit ready adjustment in radiation energy to suit the application. On the other hand, thulium sources appear to produce radiographs of a quality that is acceptable for many purposes, and they can be used at locations where standard X-ray facilities could not easily be made available.

Thulium characteristics. The use of thulium radiations has been suggested by several British workers (*1-4*). Thulium has a thermal absorption cross-section of 118 barns, with a half-life of 129 days (*5*). Measurements at Argonne suggest that there is also a small amount of resonance neutron absorption, corresponding to a resonance absorption integral of 1,500 barns, for a thin sample. In most irradiations, this resonance absorption is negligible.

The decay scheme and spectrum of thulium-170 hard radiations are shown in Fig. 3.

As a practical matter, the exact energy spectrum of the gammas and X-rays emitted from a thulium sample will vary with the size of the sample and clad thickness, but the 53.1-kev X-rays from ytterbium are far the most intense source of radiation. A typical energy spectrum of the hard emission from a thulium source and from an X-ray tube is shown in Fig. 3. We have been unable to find any other radioisotope comparable to thulium as a source of radiation of this energy.

Thulium radiations fall in the region of maximum photographic effect per roentgen. For this reason, exposures of only about 7 mr are required to blacken Eastman "Blue Brand" X-ray film in a "Patterson Par Speed" fluorescent cassette. About 50 mr of thulium radiation will blacken no-screen X-ray film. A typical 200-mg source irradiated in the MTR would have a strength of 2 r/hr at 1 ft, so an exposure of 12 sec at 1 ft would be required, using a conventional intensifying screen. Much more efficient fluorescent screens are now available, so that correspondingly shorter exposures may be possible.

The radiations from thulium have a penetrating power comparable to those from a 100-kv X-ray tube, and for this reason radiographs of thin sections are deficient in contrast.

Studies on the biological effect of thulium radiations have been carried out at Argonne by P. F. Gustafson. In this work, the effect of the radiation on a rat tumor was measured. The biological effect of this radiation was found to be comparable to equal roentgens of other types of radiation.

Availability and production. Within the last year, thulium has become available in metallic form at reasonable cost. The Materials Testing Reactor provides an excellent facility for preparation of high-specific-activity sources.

Since thulium is a rare and expensive material, it is desirable to utilize a sizeable fraction of the active atoms. This can be accomplished by irradiating thulium sources for about a half-life in the maximum available neutron flux. At a flux of 2×10^{14}, which is obtainable in the MTR, about 25% of the thulium atoms would be activated during an exposure of one half-life. While it would be desirable to have several times the flux now available, there would be no advantage to be gained by irradiating at over 10^{15}. It is also apparent that not over four times present specific activities can ever be obtained.

No difficulty was encountered in irradiating the samples in the MTR. Samples were pressed into thin aluminum containers that were welded shut. These containers are shown in Fig. 2. The containers were accommodated in a capsule to fit into MTR irradiation holes. Because of the low energy of this radiation, little shielding was required around the samples during their return from the reactor. In most cases 1 in. of lead is sufficient. Since the samples were small and easily accommodated in the irradiation facility, the irradiation costs might be expected to be low. At the time this article was written, AEC Isotopes Branch did not quote a price for radiothulium. If the price per active atom were the same as is now quoted for radiocobalt, then the thulium sources used in the X-ray unit would cost about $170.

Unit design and use. To utilize these thulium sources to best advantage, this laboratory has designed and constructed shielded containers incorporating a safe and convenient method for making radiographs with these sources. This container, shown in Fig. 1, weighs 3.1 kg. The dose rate at the surface of the unit is about 75 mr/hr.

Typical radiographs of a hand, an ankle, and dental work are shown in Fig. 4. It can be seen that acceptable detail can be obtained with thulium radiations.

Thulium X-ray units can also be used for inspection of thin castings for defects. Thulium radiations are most useful in the range of thickness up to 1 in. of steel, or 3 in. of aluminum.

Thulium units can be used to measure the density or height of liquids. In this application we have obtained precision of 5% in the continuous measurement of the volume fraction of steam within a 4-in. water tube.

II. Methods for Preparing Thulium Oxide or Metal

By F. H. SPEDDING, A. H. DAANE, and J. E. POWELL

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THULIUM, ELEMENT 69, is one of the rarest of the rare earths. It occurs in very minute quantities in a number of rare-earth ores. One of the most desirable of these, and the one with which we prefer to work, is gadolinite, a dense black silicate rock.

This rock, or concentrated ore, is ground to a coarse powder of approximately 50-mesh size and then leached a number of times with strong nitric acid. The acid leachings, which contain practically all the rare earths, are boiled down to remove most of the acid and then diluted with water until the acid concentration is a few tenths normal. The mixed rare earths are next precipitated as oxalates by means of oxalic acid. The washed oxalate precipitate is ignited to oxide; this in turn is dissolved in hydrochloric acid to give a fairly strong, mixed rare-earth chloride solution.

The original gadolinite contains about $\frac{1}{4}$% thulium. If only the thulium is desired, the thulium and other heavy rare earths are separated from the light rare earths and yttrium by complexing 15% of the rare earths present with ethylenediaminetetraacetic acid (EDTA) (*6*) and pouring the mixture rapidly through a thin bed of ion-exchange resin. The heavy rare earths are then separated on ion-exchange columns by the EDTA elution method (*7*). While this separation can also be accomplished by the citrate elution process (*8*), we have found the separation by the EDTA method to be much cleaner and much more rapid. The thulium can be precipitated from the eluate with oxalic acid, and the bulk of it is obtained in better than 98% purity, provided sufficient quantities are handled at one time. If higher purity is desired, the process can be repeated again using the partially purified thulium.

To prepare the metal, the oxide obtained from igniting the oxalate is converted to the fluoride. The latter is reduced with calcium in an argon atmosphere (*9*). This metal is then remelted to distill out any excess calcium and traces of ytterbium that might be present.

The metal is a silvery-white metal that machines readily and has a density of 9.3 gm/cm^3. The metal melts at approximately 1,600° C and has an appreciable vapor pressure at this temperature.

The commercial price for this material will depend greatly on the quantities produced, but with the present price of ore it is likely to be somewhere between $5.00 and $100.00 per gram. The smaller cost will be approached when appreciable quantities are being made and when the other rare earths in the ore can be sold as byproducts.

4 RADIOGRAPHS of hand, foot, and dental work that provide satisfactory, if not ideal, detail

III. Clinical Radiography with a Tm^{170} Source

By ROBERT J. HASTERLIK

Argonne Cancer Research Hospital University of Chicago, Chicago, Illinois

AS PREDICTED by Mayneord (*2, 3*), it is now possible to accomplish clinical radiography using a Tm^{170} source with exposure times that are feasible from a practical standpoint.

The thulium-oxide source, furnished by Argonne National Laboratory, was calibrated as yielding a dose rate of about 75 r/hr at 1 in. The unit was self-contained in a lead shield; the shutter was controlled remotely.

Preliminary studies have been completed using radiography cassettes containing mid-speed intensifying screens and arranged with all combinations of the following factors: with and without grid-fronts, with and without backing of the cassettes with $\frac{1}{16}$-in. of lead, and at 30- and 15-in. source-object distances.

Radiographs of the skeleton of a hand and wrist contained in a tissue density wax phantom and of a quality suitable for the easy detection of fractures have best been produced by using a lead-backed cassette without a grid-front, at 15-in. source-object distance, and with an exposure time of 30 sec.

A thulium source with an anticipated dose rate at least four times greater is now in preparation. Using high-speed intensifying screens with the higher activity source, it is anticipated that radiography of the extremities can be accomplished with exposure times of 1 to 3 sec.

* * *

Argonne National Laboratory is operated for the U. S. Atomic Energy Commission by the University of Chicago. The work described by F. H. Spedding et al., in section II of this article, was performed in the Ames Laboratory of AEC; section II is a contribution from the Institute for Atomic Research and Dept. of Chemistry, Iowa State College.

BIBLIOGRAPHY

1. R. West, NUCLEONICS **9,** No. 3, 76 (1951)
2. W. V. Mayneord, *Lancet* **1,** 276 (1952)
3. W. V. Mayneord, *Brit. J. Radiol.* **25,** 517 (1952)
4. R. West, NUCLEONICS **11,** No. 2, 20 (1953)
5. D. J. Hughes *et al.*, BNL-170 (1953)
6. E. J. Wheelwright, F. H. Spedding, *J. Am. Chem. Soc.* **75,** 2529 (1953)
7. F. H. Spedding, J. E. Powell, E. J. Wheelwright, *J. Am. Chem. Soc.* (to be published)
8. F. H. Spedding, J. E. Powell, ISC-349 (1953)
9. A. H. Daane, F. H. Spedding, *J. Electrochem. Soc.* **100,** 442 (1953)

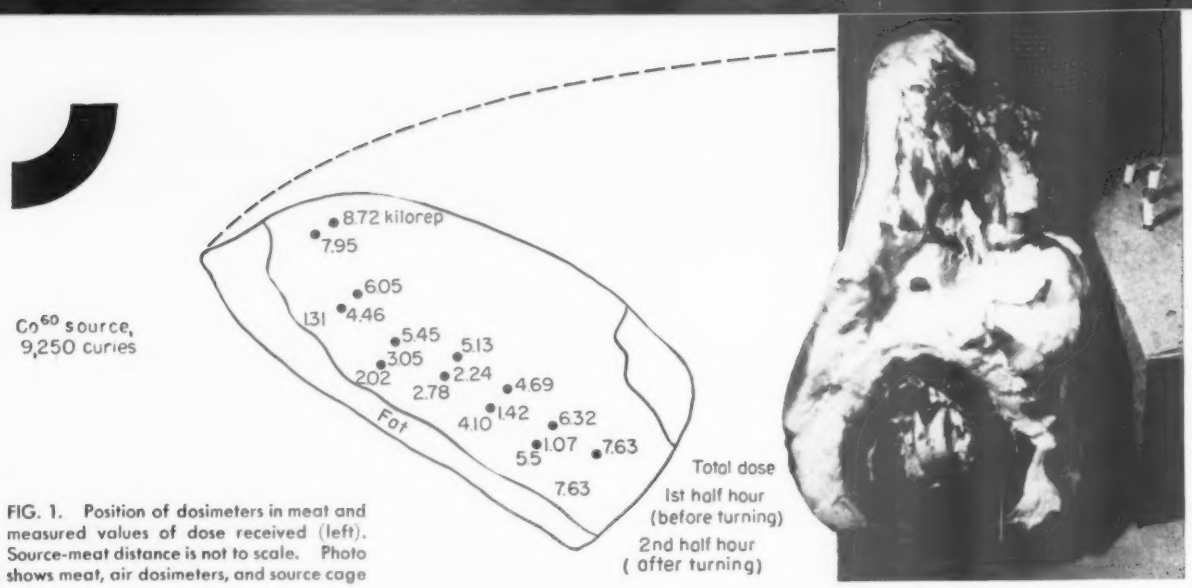

FIG. 1. Position of dosimeters in meat and measured values of dose received (left). Source-meat distance is not to scale. Photo shows meat, air dosimeters, and source cage

Using Co^{60} and Fission Products

Experiments with full-weight hog sections show the technical practicality of using radiation to break the trichinosis cycle. Results with 2-yr-old reactor fuel slugs confirm broad-beam calculations with 12-in. half-value layer in water

By H. J. GOMBERG,*† S. E. GOULD,†‡ J. V. NEHEMIAS,§ and L. E. BROWNELL§
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GAMMA RAYS from the 10-kilocurie Co^{60} source at the University of Michigan and from old NP (Hanford reactor) fuel slugs that were in storage at the National Reactor Test Station, Idaho Falls, Idaho, have been used to study the feasibility of controlling trichinosis by irradiation of pork. This article deals primarily with the techniques and dosimetry of these tests.

Use of radiation for trichinosis control has been under investigation for some time (*1–10*). About 750,000 to 1,000,000 rep are needed to kill trichinae *in situ* (*6, 7*). But 20,000 rep of Co^{60} gamma rays will prevent maturation of the larvae to adults, and 12,000 rep will sterilize the females, preventing reproduction (*7*). Either of these latter effects will control trichinosis without the high radiation cost or deleterious flavor changes associated with a killing dose (*11*).

Slightly lower doses of 200-kv X-rays produce similar results (*5, 6*).

All these results, however, were obtained in laboratory experiments that do not approach practical conditions. During processing, the hog carcass is gutted, split, and then cooled for 24 hours before cutting. This delay period was selected as a suitable time for irradiation, and the tests described here were designed to simulate processing at this point.

Cobalt-60 Tests

While referred to as a 10-kc source, the Co^{60} source is nominally rated at 9,250 curies as of December, 1952. Measurements and calculations indicate that, when self-absorption is considered, the activity is 28–33% of the nominal value (*12*).

Previous dose distribution studies show that this source can be treated as a point at distances beyond 10 in.

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‡ Departments of Pathology: University of Michigan; Wayne County General Hospital Eloise, Mich.; and Wayne University College of Medicine, Detroit, Mich.
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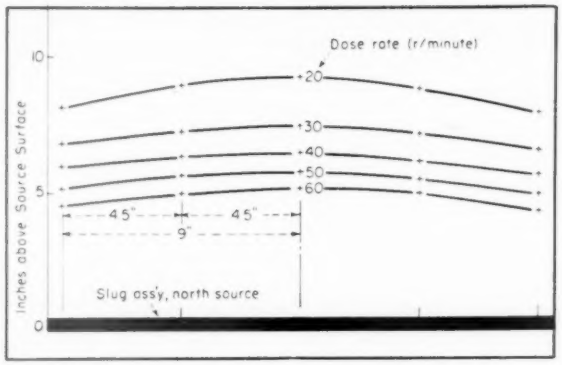

FIG. 2. Isodose curves derived from spot measurements over central plane of array of old reactor fuel slugs under water

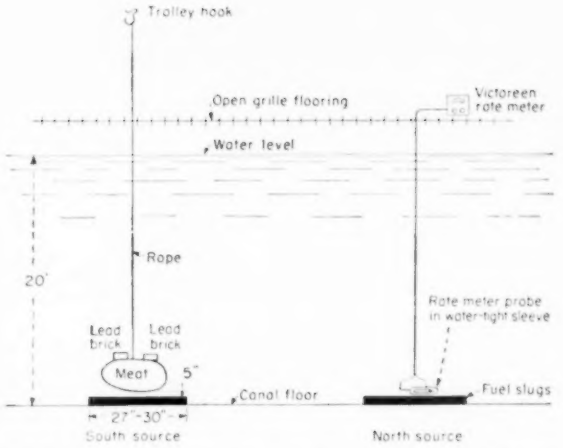

FIG. 3. Irradiation arrangement used with old reactor fuel slugs in canal

in Pork Irradiation Experiments

from its surface (*12*). All of the meat irradiated was located 13 in. or more from the source surface. With the dose distribution in air known, an appropriate half-value layer for Co^{60} radiation in meat can be used to calculate the dose at any point in the hog section.

Procedure and dosimetry. The most significant test of the cobalt series was made with the hog section oriented so that the length along a radius was 14 in. The whole section, a hind quarter of a 450-lb hog, weighed about 55 lb and measured about 14 by 8 by 16 in. The section was oriented so as to obtain maximum variation in the dose delivered to various depths of the section. The meat was irradiated with the center of the section 17 in. from the source surface for ½ hr, then rotated through 180 degrees and irradiated for a second ½ hr.

In addition to dose determination by calculation, ferrous-sulfate dosimeters were inserted in the meat at 2-in. intervals so that an independent dose check could be made. Three sets of dosimeters were used, one during the first period, a second following rotation, and a third remaining in place for the full hour.

A diagram of the source, meat and dosimeters is given in Fig. 1; the experimental arrangement is also shown. The wire cage surrounds the source when it is in operating position. A set of four calibration (in air) dosimeters also was used.

Fission-Product Tests

In an attempt to simulate possible large-scale operations, arrangements were made to irradiate hog quarters, using old reactor fuel slugs. While it was desired to use principally cesium-137 radiation, the oldest slugs available were about two years old. According to Hunter and Ballou (*13*), the gamma radiation energy for two-year-old fissioned uranium is 86% 1.2 Mev from Pr^{144} and 14% 0.6 Mev, approximately, from Ba^{137} and Rh^{106}. Although the spectrum is, therefore, close to that of the cobalt already used, the experiment was carried out to study the effect of differences in operating conditions.

The fuel rods were assembled into two rectangular arrays at the bottom of the 20-ft-deep water canal in the storage building. The resultant plaques were about 30 in. long and 27 in. wide, the packing being as tight as possible with the 20-ft poles used for manipulation.

Before irradiation tests were made, the radiation field was mapped using a Victoreen roentgen rate meter. The probe was enclosed in polyethylene tubing and weighted so that it would sink. The weight was located so that no scatter radiation from it would reach the measuring thimble. The probe was then lowered through the water and held at various known positions above the source.

Isodose curves derived from these tests are shown in Fig. 2 for one source. The isodose surfaces closely approximate surfaces generated by rotating these curves in a horizontal plane about the central axis of the source. The variation of dose with distance from the plaque surface was analyzed mathematically and is commensurate with radiation having a 12-in. half-value layer in water. (See the appendix at the end of this article.)

Taking Compton secondaries into account, this is the half-value layer of both 0.6 Mev and 1.2 Mev gamma radiation in water (*14*). The measurements and calculations thus serve to check each other.

Procedures and dosimetry. Two sections, a hind quarter and a fore quarter, of a hog carcass containing encysted trichinae were used for the

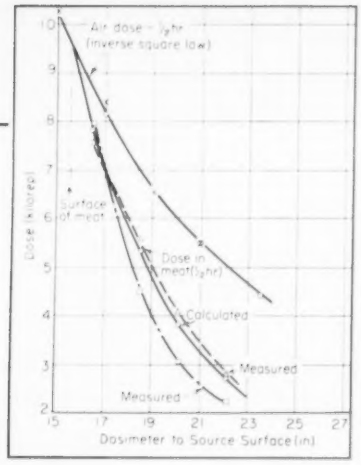

FIG. 4. Dose in air and at corresponding points in meat for Co^{60} source. Calculated dose based on 8-in. half-value layer. It is assumed that space attenuation follows inverse square law. Ferrous-sulfate dosimeter readings corrected for Lusteroid container

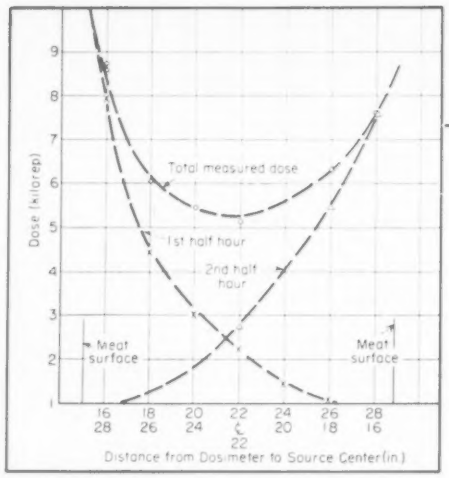

FIG. 5. Measured dose delivered to pork 14-in. thick by Co^{60} source whose center was 15 in. from nearest surface of meat. Ferrous-sulfate dosimeter readings corrected for Lusteroid container

test irradiation. Before irradiation, Lusteroid vials containing ferrous-sulfate solution were inserted into the pork so that the dose distribution within the meat could be determined. The sections were then wrapped in thin plastic sheets to minimize water-logging of the meat, weighted so that they would sink, and lowered at the end of a rope into the canal. The rope was tied off when, to the best estimate, the bottom surface of the meat was 5 in. from the radiating surface. The average dimensions of both sections were 15 by 20 by 8 in. A sketch of the experimental arrangement is shown in Fig. 3.

Because of shrinkage of the rope, and water currents in the canal that shifted the sections with respect to the irradiators, exact conditions could not be maintained throughout the exposures. The exposure times for the sections were selected so that the bottom layer of the second section, which received the largest dose in that section, would be slightly more heavily irradiated than the top layer of the first section. In this way the two sections would show a wide range of dose distribution, with a small overlap. The second section was irradiated for 320 minutes and the first section for 1,185 minutes.

In addition to checking dose rate as a function of position with respect to the source, several dosimeters, Lusteroid and glass, were attached to the Victoreen probe and lowered into the water to fixed positions either before or after the meat irradiation. From these tests it was found that the glass ferrous-sulfate dosimeters gave results 76 as high as the Victoreen meter reading. The same factor was observed in the cobalt source calibration (*12*). It was also found that the ratio of glass-dosimeter to Lusteroid-dosimeter readings was 0.55, due apparently to an oxidizing agent produced by irradiation of Lusteroid. In our dosimeters, which contained aerated solutions, the maximum dose measurable before the dissolved oxygen was exhausted was about 25,000 r for glass or 13,750 r for Lusteroid.

As discussed in the section on results, when correction was made for shifting of the meat, the agreement between the dose predicted from known dose distribution in water, and the dose measured in the meat by dosimeter, was quite satisfactory.

Cobalt-60 Results

A comparison between the calculated dose in meat and the measured dose delivered by the cobalt source for two separate half-hour runs is given in Fig. 4. The agreement is considered satisfactory for the experimental conditions.

The doses measured in the meat are shown in Fig. 5. The most significant result is the final dose distribution in the meat after rotation. The total variation is about 2 to 1 from the surface to the interior for a section 14-in. thick. Of this change, only 20% is due to attenuation by the absorption in the meat; the rest is caused by the geometry of the source and field.

These results could be checked quite closely by calculation, using an 8-in. half-value layer for the cobalt gammas in meat. As an example, the calculated dose at the center of the meat was 5,225 r and the measured value 5,130 r.

A second calculated dose distribution in a slab 14-in. thick, based on an 8-in. half-value layer but no geometric attenuation, indicates a dose variation of 12.5% from surface to the interior. This is a limiting value, never quite attainable in practice.*

Fission-Product Results

The hind quarter of the carcass was irradiated for 320 minutes, providing measured doses up to about 9,000 r to the dosimeter closest to the irradiator. This dose was somewhat lower than had been estimated for the selected position of the meat. Analysis of the data obtained from the dosimeters showed that, due to unequal buoyancy,

* Comparison of these results with the work of Crean *et al.* (*15*) was discussed in a recent "Letter to the Editor" (*16*).

the section had rolled slightly, so that the isodose surfaces in the meat were not quite parallel to the bottom surface of the meat slab. Also, by checking the dose distribution in water as determined by the Victoreen rate meter against that given by the dosimeters in the meat, it is estimated that the bottom of the meat was 8 rather than 5 in. from the source. This is not hard to explain, as positioning of the meat was done at the end of a 20-ft rope. Since the dose rate changes fairly rapidly in this region (Fig. 2), the dose received was noticeably affected. Fortunately, the dosimeters provided correct dose data so that the biological effectiveness could be measured accurately.

The fore quarter was irradiated for 1,185 minutes to provide doses originally intended to overlap slightly the dose range in the hind quarter and go up from there. Actually, because of the low dose in the hind quarter, there is a break, from 9,000 to 13,000 r, the dose indicated by the dosimeter in the fore quarter farthest from the irradiator.

At the time of this experiment, it was not known that the Lusteroid dosimeters would saturate at about 13,750 r. This information, cited earlier, came from this test. As a result, most information on the dose rate in the meat was obtained by calculation. However, the check between those dosimeters that did not saturate and the predicted dose for their position fell well within experimental error.

Biological Effects

In this series of tests, the effectiveness of irradiation in preventing trichinosis infection was also determined. For each radiation level, 5,000 larvae recovered from the irradiated meat were fed by stomach tube to rats. Another group of rats was fed 5,000 larvae from nonirradiated meat as a control.

By using techniques described elsewhere (*6*), the number of adult females with young in the small intestine 6 days later and the number of encysted larvae in the muscles of the rats 30 days later were determined. Results are shown in Figs. 6 and 7.

With Co^{60}, sterilization of the trichina larvae is complete at a dose somewhat higher than 10,000 r (Fig. 6). This is in accord with results of studies of small sections of pork and rat carcasses (*7*). The very rapid depression in the number of encysted trichinae (Fig. 7) is significant. The best fit to the data appears to be a straight line, implying that inhibition of encystment is a "one-hit" effect.

Both Figs. 6 and 7 indicate that sterilization was not complete at the highest dose received in the Co^{60} experiment. In a similar test, a dose of 12,000 r resulted in complete sterilization of the females and complete absence of encysted trichinae in the test rats. Doses were calculated in this test and were not measured with dosimeters.

In the fission-product tests, complete sterilization and prevention of infection occurred at 10,000 r. Data for these curves came entirely from the first or hind-quarter test. The fore quarter, which received a minimum dose of 13,000 r, yielded larvae that were all completely sterile, if they developed at all. No rat receiving these larvae showed any infection.

Discussion

The effectiveness of gamma radiation for breaking the trichinosis cycle has been demonstrated using full-weight sections of a hog carcass. These results are easily extrapolated to irradiation of a full-weight carcass.

Using a properly designed irradiator plaque in air, irradiation of hog carcasses in a routine manner is perfectly feasible.

Further studies on the cost of this process, using cobalt-60, cesium-137, and other radiation sources are now reaching completion. These results, including a tentative design of a plant for carrying out the processing, will be published shortly.

Appendix

Radiation intensity along the axis and half-value-layer calculations for circular plane sources in an absorbing medium. Assume that the source is a large circular disk and that the radiation intensity at any point along

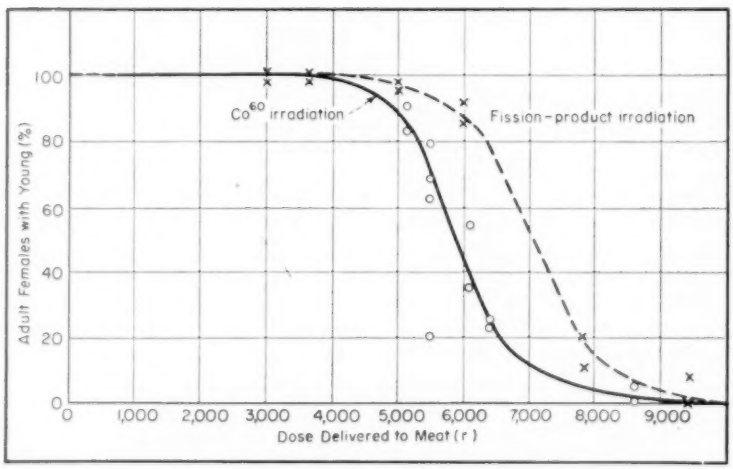

FIG. 6. Sterilization of trichinae in pork by Co^{60} and waste fission-product irradiation. Dose measured by ferrous-sulfate dosimeters (Lusteroid). Female adults recovered from rat gut 6 days after rat was fed irradiated larvae

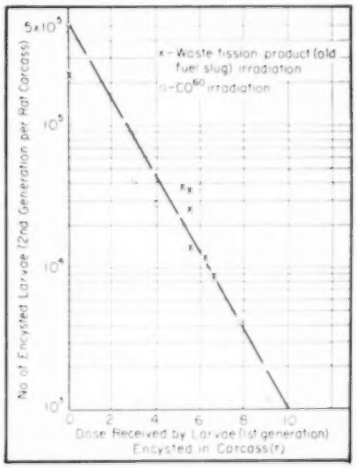

FIG. 7. Larvae in rat muscle 30 days after feeding 5,000 irradiated larvae

the axis is the scalar sum of contributions from all points on the disk.

In a nonabsorbing medium

$$dI = \frac{2\sigma\pi r\, dr}{R^2 + r^2} \qquad (1)$$

where σ = source strength per unit area, r = radial distance from source axis to point on the source disk, and R = distance along axis from source disk to point at which intensity is being measured. Integrating

$$I = \sigma\pi \log_e \left(\frac{R^2 + r^2}{R^2}\right) \qquad (2)$$

where r_1 is the radius of the disk.

In an absorbing medium, assuming monochromatic radiation or equilibrium conditions

$$dI = \frac{2\sigma\pi r\, dr}{R^2 + r^2} e^{-\lambda(R^2+r^2)^{1/2}} \qquad (3)$$

where the last term represents the attenuation by absorption of radiation from any element of the disk to the point on the axis being studied. Let $(R^2 + r^2) = y$, then

$$dI = \frac{\sigma\pi e^{-\lambda y^{1/2}}}{y}\, dy \qquad (4)$$

Expand $e^{-\lambda y^{1/2}}$ as a series

$$dI = \frac{\sigma\pi}{y}\, dy \left(1 - \lambda y^{1/2} + \frac{\lambda^2}{2!} y \cdots\right) \qquad (5)$$

Integrating

$$I = \left| \sigma\pi\,(\log_e y) - 2\lambda y^{1/2} + \left(\frac{2\lambda^{1/2} y}{2 \cdot 2!} - \frac{2\lambda^3}{3 \cdot 3!} y^{3/2} \cdots\right)\right|_{y=R^2}^{y=R^2+r^2} \qquad (6)$$

$$I = \sigma\pi \left[\log_e \frac{R^2 + \lambda_1^2}{R^2} - 2\lambda \left\{([R^2 + r^2]^{1/2} - R) - \frac{\lambda}{4} r^2 - \frac{\lambda^2}{18}() \cdots\right\}\right] \qquad (7)$$

Equation 7 is seen to be similar to Eq. 2 except for the correction terms in the curly brackets. If, from trial solutions, λ is substantially less than one, only the first term within the curly brackets is significant.

Trial solutions to determine the value of λ can be made by taking measured intensity values from tests as shown in Fig. 3. From the physical dimensions of the system: (*a*) $r_1 = 13$ in., $R_1 = 5$ in., $I_1 = 64$ r/min; (*b*) $r_2 = 13$ in., $R_2 = 9$ in., and $I_2 = 22$ r/min.

Substituting first (*a*) then (*b*) in Eq. 7, but retaining only the first terms in the brackets, and solving for λ

$$\lambda = 0.057 \text{ in.}^{-1} \qquad (8)$$

This value of λ justifies the assumption that only the first term within the brackets is important.

A second order approximation, using the second group of terms in the brackets leads to

$$\lambda = 0.0608 \text{ in.}^{-1} \qquad (9)$$

This serves as a further check on the assumptions.

From the value of λ, the half-value layer for the radiation is

$$T_{1/2} = 12.1 \text{ in. from } \lambda = 0.057 \quad (10)$$
$$= 11.4 \text{ in. from } \lambda = 0.061$$

These values, the half-thickness for the fuel-slug gamma radiation under water, check very well with the predicted value of 12 in. See text for radiation spectrum and references.

To study further the effect of the water on the radiation field, calculations using Eq. 7 were made for the intensity of radiation 5 in. from the center of a disk source under water as the disk becomes larger. The results are shown in Fig. 8. It is apparent that a limiting value is soon reached so that increasing the source diameter no longer contributes to the radiation intensity along the axis. This arises simply because radiation from the outer rings of the source plaque is very heavily attenuated by the medium. It will be seen that, for 5-in. spacing, the maximum useful source radius is about 13 in., approaching the values used in our experiment quite closely.

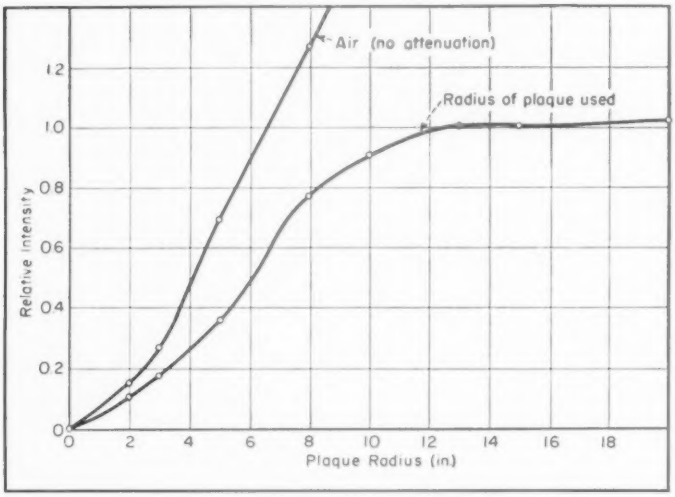

FIG. 8. Variation of radiation intensity at point 5 in. directly above center as radius of plaque is increased. Plaque under water (half-value layer 12 in.)

* * *

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BIBLIOGRAPHY

1. B. Schwartz, *J. Agri. Research* **20,** 845 (1921)
2. J. E. Semrad, *Am. J. Roentgenol.* **38,** 470 (1937)
3. A. J. Levin, T. C. Evans, *J. Parasitol.* **28,** 477 (1942)
4. J. E. Alicata, G. O. Burr, *Science* **109,** 595 (1949)
5. J. E. Alicata, *J. Parasitol.* **37,** 491 (1951)
6. S. E. Gould, J. G. Van Dyke, H. J. Gomberg, *Am. J. Pathol.* **29,** 323 (1953)
7. H. J. Gomberg, S. E. Gould, *Science* **118,** 75 (1953)
8. H. J. Gomberg, S. E. Gould, "Proceedings of the 1952 National Conference on Trichinosis," *Pub. Health Reports* **68,** 419 (1953)
9. H. J. Gomberg, S. E. Gould, "Proceedings, 1953 Conference on Nuclear Engineering" (University of California, Berkeley, 1953)
10. S. E. Gould, H. J. Gomberg, F. H. Bethell, *Am. J. Public Health* **43,** 1550 (1953)
11. L. E. Brownell *et al.* Utilization of gross fission products, progress report 3, CO0-191 (1952)
12. J. G. Lewis, J. V. Nehemias, D. E. Harmer, J. J. Martin, NUCLEONICS **12,** No. 1, 40 (1954)
13. H. F. Hunter, N. Ballou, NUCLEONICS **9,** No. 5, C-2 (1951)
14. J. L. Balderson *et al.*, AECU-2934 (1948)
15. L. E. Crean, P. J. Isaacs, G. J. Weiss, F. Fahnoe, NUCLEONICS **11,** No. 12, 32 (1953)
16. H. J. Gomberg, L. E. Brownell, J. V. Nehemias, NUCLEONICS **12,** No. 3, 82 (1954)

Fast-Neutron Scintillation Survey Meter

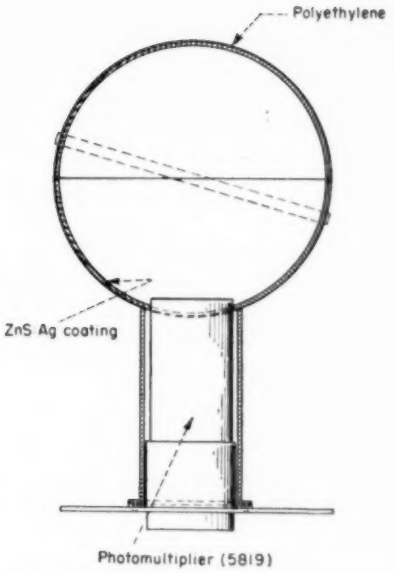

FIG. 1. Sphere assembly of fast-neutron scintillation survey meter

To estimate the biological hazard caused by fast neutrons, a proton-recoil scintillation counter has been developed. The instrument gives a sizable response at low flux levels, has good gamma discrimination, and is nondirectional

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ESTIMATING the radiation hazard contributed by fast neutrons presents certain difficulties. The permissible flux is very low and the methods of detection are inefficient, as they depend upon nuclear cross sections. Gamma rays are usually present in neutron fields and must be either accounted for or excluded from detection. In addition, measured fluxes are difficult to interpret in terms of biological damage.

An approach to this measurement problem is the proton-recoil scintillation counter described in this article (Fig. 1) (*1*). It is a highly sensitive instrument, with good discrimination against gamma detection, and gives a sizable response even at tolerance flux levels.

Counter Theory

An attempt is made to estimate the biological damage caused by a neutron flux by measuring the energy-flux density, i.e., the product of the number of neutrons and their energy integrated over the appropriate spectrum. This approximation is used chiefly because it is readily measurable, especially in low-level neutron fields. From a biologist's viewpoint, measurements of other physical factors (*2*) are more desirable, but in fast-neutron counting these measurements are impossible or difficult at tolerance levels.

In a proton-recoil counter, if the range of the most energetic recoil is less than the thickness of the radiator, then the efficiency is approximately proportional to the neutron energy. Mather (*2*), using this principle, developed a proportional counter and a technique to estimate the energy-flux density.

Calculations of recoil counter efficiencies under various physical conditions are familiar (*1, 3, 4*). In particular, Moyer (*1*) has derived a relationship for a hydrogenous slab irradiated by neutrons not homogeneous in energy. Assuming that the slab thickness is greater than the maximum recoil-proton range and that all recoil protons emerging from the slab are detectable, the counting rate (cps), according to Moyer, is

$$C = (1.0 \times 10^{-27}) N_H A \int_{E_{min}}^{E_{max}} \phi(E) E \, dE \quad (1)$$

where N_H is the number of hydrogen nuclei/cm^3, A is the area of the slab face, E is the neutron energy, and $\phi(E)$ is the neutron-flux density within unit energy interval at E. Thus, the count-

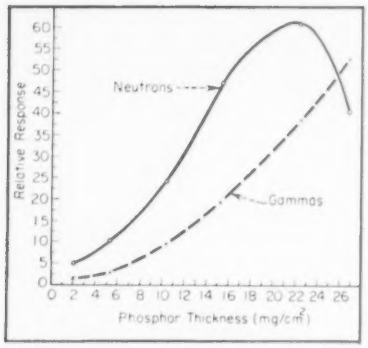

FIG. 2. Phosphor sensitivity

ing rate C (cps) is approximately proportional to the energy-flux density delivered by fast neutrons (Mev/cm²/sec).

This simplified picture must be modified by the fact that not all proton recoils are detectable above the bias level, which is set instrumentally to reject Compton electrons. Because of this, the simple proportionality demonstrated above begins to break down for decreasing neutron energies, usually at about 0.5 Mev (depending of course upon the actual bias adjustment) (see Fig. 6, ref. *1*). Typically, the bias adjustment is set within the limits 0–0.2 Mev. For the scintillation instrument described here, the bias energy can be considerably less than 0.2 Mev if gamma-radiation levels are not too high.

Admittedly, the energy-flux density delivered by fast neutrons is not precisely the most desirable physical quantity from which to interpret the biological hazard. But if the mean energy, E_m, of the neutrons is known, or can be estimated, it is possible to immediately infer the numerical flux density of the fast neutrons by

$$\phi_{\text{total}} = \int \phi(E)\, dE = \left(\frac{1}{E_m}\right) \int \phi(E) E\, dE$$

or, in view of Eq. 4

$$\phi_{\text{total}} = \frac{C}{(1.0 \times 10^{-27}) N_H A E_m} \quad (2)$$

Precise evaluation of E_m demands, of course, knowledge of the neutron spectrum in the region under survey. This is difficult to obtain with neutron field intensities as low as the order of tolerance levels. Nevertheless, estimates of E_m are possible by considering the character of the original neutron emission (i.e., line spectrum, fission spectrum, evaporation spectrum, *et cetera*), and the moderating effects of shielding. Rough experimental estimates of E_m can be obtained from paraffin moderation tests employing a thermal detector.

The instrument described here is useful because of its sensitivity and its selective response to fast neutrons. Its utility in inferring flux densities or biological hazards is only as good as the ability of the operator to estimate the mean energy of the neutrons or to interpret the biological effects from energy delivered across the surface of a medium by fast neutrons of unknown spectrum. It has, however, proved to be very useful in fields near tolerance intensities where a rough estimate of E_m could also be made.

Counter Construction

A sphere is chosen as the geometry best suited for measuring fluxes of unknown direction. Two hollow hemispheres are formed from hydrogenous material (polyethylene), coated on the inside with a suitable phosphor, and then joined together to form a sphere. The neutron-induced proton recoils produce scintillations in the phosphor, which are viewed with a photomultiplier through an aperture. The thickness of hydrogenous material can be chosen with respect to the energy interval of interest. It is convenient to have the thickness greater than the range of the highest-energy recoil proton, providing neutron energies do not extend too high. To cover an energy interval from 0.1 to 20 Mev, ⅛ in. is quite satisfactory (*1*).

Forming the polyethylene into hemispheres can be done readily by molding from sheet stock. An experimental model 7 in. in diameter with a ⅛-in. wall thickness was made from a sheet of ¼-in. polyethylene 9½ in. in diameter. The mold and plastic were preheated to 135° C, assembled, and pressed out. The mold was lightly coated with silicon grease to prevent sticking.

The two spheres are cleaned and coated with a thin layer of ZnS:Ag (RCA phosphor 33Z20A). A Paasche air brush is used to spray the mixture of absolute alcohol, Duco cement and the phosphor. The ratios are not

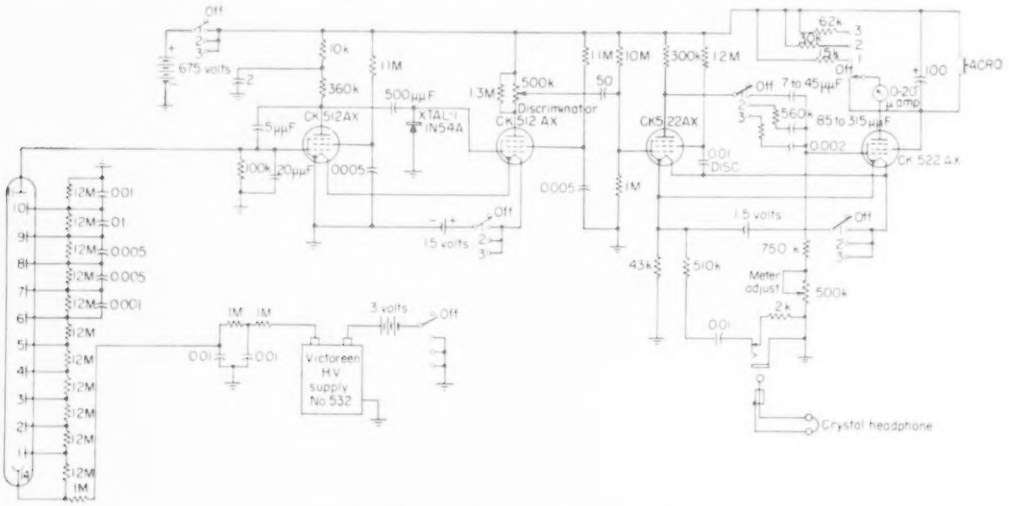

FIG. 3. Circuit of fast-neutron survey meter

critical, but a workable mixture is 1.5 gm Duco to 100 gm alcohol. Then to 17 gm of the above mixture, 75 gm of ZnS:Ag is added. The phosphor is kept in suspension by shaking the air brush slightly while spraying. It is well to use a large ratio of liquid to air to insure wetting and sticking. The amount of phosphor is not critical, as shown by Fig. 2, which indicates the variation of sensitivity with gammas and neutrons; 18–22 mg/cm² is an average coating thickness for maximum sensitivity.

The neutron flux levels to be measured determine the size of the sphere. Because of the natural diffusing surface of the ZnS:Ag, little loss of light occurs as the size of the sphere is increased. The diffusing surface also makes the counter equally sensitive around its periphery, with the exception of the photomultiplier aperture. With the present RBE and low fast-neutron tolerance, it is desirable to have a highly efficient counter while still keeping it practical and portable. Using counting-rate circuitry, a lower limit of a few counts per second can be read with accuracy. A practical design is to have a 5 sec counting rate equal to the minimum neutron-flux tolerance.

If this minimum for full scale on the most sensitive range is approximately 100 Mev/cm²/sec, then using Eq. 1

$$C = K\int\phi(E)E\,dE$$

Recalling $K = N_H A\sigma_{np}(E)R(E)$, where $R(E)$ is the range of a proton of energy E in polyethylene, and substituting numerical values, one finds 15 cm as the approximate diameter of the sphere if all the protons are counted and there is no aperture. Actually about 70% of the protons register counts and the opening for the photomultiplier is 20 cm². Allowing for these losses, the sphere should be about 17 cm in diameter.

The inside surface of the sphere is viewed with a 5819 or 6292 photomultiplier through a suitable aperture as shown in Fig. 1. The pulses are fed into a two-stage amplifier that employs a crystal limiter and a feed-back network. The pulses vary from 7 mv to 700 mv, making some form of limiter necessary. An examination of Fig. 3 shows that the pulse is not limited but that merely the undershoot is conducted away—in effect preventing saturation by eliminating overshoot.

From the amplifier the selected pulse

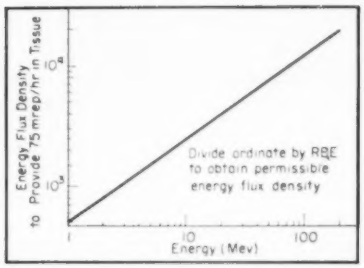
Energy Flux Density to Provide 75 mrep/hr in Tissue
Divide ordinate by RBE to obtain permissible energy flux density
Energy (Mev)

FIG. 4. Neutron permissible energy-flux density

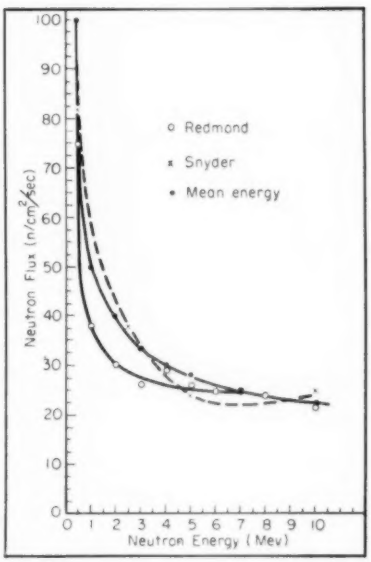

FIG. 5. Permissible neutron flux

amplitude triggers a univibrator (*5*). The "discriminator" is set high enough to bias out the gamma-electron pulses while allowing most of the pulses induced by proton recoil to start the multivibrator action. Each time the circuit is triggered, a pulse of current is put into a meter integrating circuit, which averages the pulses into a meter reading. The width of the univibrator pulse is necessarily long at low counting rates. On the most sensitive scale it is a few hundred microseconds—this actually represents the "dead time" of the counter and limits the use somewhat around a pulsed accelerator (*6*, *7*) at high radiation levels. For most practical conditions where shielding is present, and the duty cycle of the accelerator is not too short with respect to the duration of the univibrator pulse, there is very little inaccuracy in the meter's representation of the energy-flux density.

Magnetic shielding of the photomultiplier is provided by making the light shield of soft iron. It is desirable to keep the weight of any portable instrument at a minimum; therefore, in cases where no magnetic fields are present (reactors, sources, *et cetera*) most of the light shield can be Al or very thin Cu.

Test and Calibration

Most of the proton pulses have greater amplitude than the electron pulses, but when one considers high gamma backgrounds and "pile-ups" the pulses can be equal in magnitude. The neutron sensitivity for practical purposes varies directly with the gamma sensitivity.* A compromise between desirable high efficiency and good gamma discrimination is to provide, for one calibration, bias for only the minimum expected gamma fluxes. Another discriminator setting and calibration curve would provide additional bias for higher gamma fluxes. With 100-mr/hr Ra γ's biased out and using PoBe neutrons, the counter sensitivity is approximately 15 Mev/cm²/sec, equivalent to 1 cps—which agrees well with the calculated value.

Figure 4 represents the energy-flux density at various neutron energies that will provide a dose of 300 mrep per 40-hr week in tissue. The ordinate should be divided by the RBE to obtain the permissible energy-flux density. The curve is a composite of available data. Figure 5 shows the agreement with Snyder's (*8*) and with Redmond's (*9*) curves of permissible flux.

The principal features of this instrument are its high sensitivity and nondirectional characteristics, allowing measurements of low neutron fluxes to be made accurately and quickly.

* This is markedly a function of the energies in both cases.

* * *

The author wishes to thank Dwight Dixon and B. J. Moyer for their helpful suggestions.

BIBLIOGRAPHY

1. B. J. Moyer, NUCLEONICS **10,** No. 5, 14 (1952)
2. R. L. Mather, unpublished (UCRL)
3. B. Rossi, H. Staub, "Ionization Chambers and Counters," National Nuclear Energy Series V-2 (McGraw-Hill Book Co., Inc., New York, 1949)
4. H. H. Barschall, H. A. Bethe, *Rev. Sci. Instr.* **18,** 147 (1947)
5. L. Nierman, MDDC-725 (1947)
6. A. Brodsky, NUCLEONICS **10,** No. 12, 36 (1952)
7. A. G. Bousquet, NUCLEONICS **4,** No. 2, 67 (1949)
8. W. S. Snyder, Biophysics Symposium, Washington, D. C., March, 1952
9. A. H. Redmond, USNRDL-348 (1952)

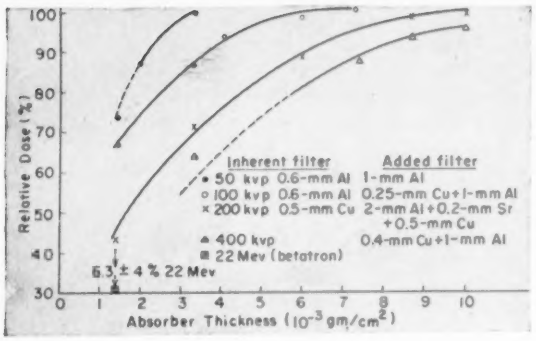

FIG. 1. Effect of X-ray energy on transition maximum

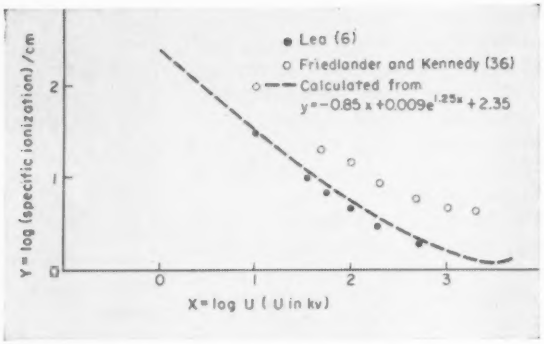

FIG. 2. Variation of specific ionization with X-ray energy

How Biological Effectiveness Varies with X-Ray Energy

A definite dependence of biological effectiveness on X-ray wavelength is shown by irradiation of bacteria (4–2,000 kv) and by results of other investigators. The relationship depends on transition effect, absorption, and specific ionization

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IT WOULD BE advantageous for biological radiation experiments to know the correlation between the physically measured amount of radiation and the actually effective energy dissipated in the biological target. This relationship can only be examined if one assumes that the biological effects in a given system are qualitatively the same for all X-radiations and, furthermore, that the biological material maintains the same conditions during all experiments. If either one of these factors is not constant, a comparison of the effectiveness of qualitatively different X-radiations is impossible.

The expression "biological dose" used in this article refers to an approximation towards such a unit of dose that the same biological effect would be obtained by a given dose, independent of the quality of the radiation.

For the determination of this biological dose, the following expression has been suggested by Failla (*1–5*)

$$D_B = D \times a \times b \qquad (1)$$

where D is the dose determined by conventional ionization measurements, a represents the quality factor in regard to the biological effectiveness of radiation, and b is a factor that should remain constant since it depends mainly on the biological conditions. Obviously, only that part of the radiation is effective that is absorbed in the biological system.

The biological effects are due to collisions of charged particles with atoms of the irradiated object. The study of these effects involves the investigation of phenomena of transition, absorption and specific ionization.* These three factors are X-ray energy dependent variables.

Transition effect. A transition effect caused by the scattered electrons attains its maximum at a depth of an absorber that corresponds approximately to the mean range of the electrons. Therefore the surface intensity of the absorbing object is not the maximum. The range of the scattered secondary electrons varies with the energy transferred to them during the interaction with the photons of the X-rays. This variation causes a change in the position of the transition maximum. Absorption curves showing build-up of dose at very high X-ray energies have been published by several authors (*6–8*). However, transition effects have also been experimentally demonstrated (*9*) at X-ray energies as low as 50 kv peak. Preliminary results of these experiments are shown in Fig. 1.

The tendency of the transition maximum to move in the direction of smaller absorber thicknesses with decreasing X-ray energies enhances considerably the probability of causing an effect in monocellular biological systems, such as bacteria.

Absorption. The wavelength dependency of the absorption coefficient μ, representing the fraction of energy

* This term is meant to include all kinds of collisions.

absorbed per cm^3 of the absorbing material traversed, is demonstrated by the equation (*10*)

$$\mu = C\lambda^n + \sigma$$

where λ is the wave length, σ the mass scattering coefficient, C a constant, and n varies from $n = 2.8$ to 3.05 depending on the absorbing material.

Specific ionization. The specific ionization of the electrons, produced during such an absorption process, become smaller and smaller with increasing X-ray energies (Fig. 2).

One would expect that at higher X-ray energies the probability of producing an effective number of ionizations in a small biological object becomes less. One can conclude, therefore, that the quality factor a is a function of λ, i.e., $a = f(\lambda)$.

This variation of specific ionization has been studied by numerous authors on a great variety of biological and other materials (*10–27, 40, 41*). However, reviewing the literature did not always result in consistent answers in respect to the biological effectiveness (*14, 19, 20*). This might be due to numerous circumstances, such as variations of the experimental procedures, changes of the biological material, and other factors that at the present time cannot be accounted for.

For reasons of comparison, we present in this article our experimental results together with a short review of data from other authors (Table 1). Our main concern is to obtain, independently, further indications in regard to the lethal effects of X-radiation of various wavelengths on biological material. It was advisable to cover a rather large range of X-ray energies to establish a significant variation in the lethal reaction of the radiation with the cells. This should enable us eventually to find a definite relationship between wavelength and biological effectiveness of the radiation.

Experiments

Experiments were carried out with X-rays of 4 kv, 39 kv, 186 kv and 2 Mev. Since bacteria allow a relatively accurate standardization in respect to experimental procedures, growth, etc., bacteria *E. Coli* (strain B) and *Pseudomonas aeruginosa* (strain $1630T_1$) were used as biological objects in our experiments. Both types of bacteria are approximately the same size and were grown under identical conditions. The purpose of the choice of two different bacterial organisms was to observe an eventual different response to the radiation.* Such a variation was found and will be discussed later.

The bacteria were sprayed on the surface of agar plates (*15, 30*). *E. Coli* was irradiated with 4, 39, and 186 kv; *P. aeruginosa*, with 39 kv, 186 kv and 2-Mev X-rays.

Irradiating equipment. The 4-kv X-ray constant potential apparatus was a laboratory-built unit (*15*) with Al anode and cellophane window. The maximum intensity of the 4-kv X-rays is at about 1.5 kv due to the Al_K radiation. No filters were employed except the cellophane window.

The dosimetry of this very soft radiation demands special attention and equipment. The dose measurements must be made in the identical position where the objects are irradiated (*31*), since air absorption of X-rays is considerable at this energy. Special ionization chambers were built for this purpose (*15, 31*), and the change of potential on the chamber electrodes caused by the ionizing radiation was determined with an electrometer.

The 39-kv and 186-kv X-irradiation of the material was carried out with standard equipment. The 39-kv unit worked at constant potential, and the X-rays were filtered only by the glass of the tube (equivalent to 0.5 mm Al). The maximum intensity was assumed to be at about 26 kv. The 186-kv X-rays were produced by a half-wave rectifying unit and were filtered by 0.25 mm Cu and 0.5 mm Al, giving an almost monochromatic radiation at about 70 kev (*32*).

The very high energy radiation

TABLE 1—Difference in Radiation Effects with Variation of X-Ray Energy

Author	λ (Å)	*kv*	*Dose giving same biologic effect*	*Object irradiated*
Holweck, Lacassagne (*28*)	8	1.5	3.7 Arbitrary units	*P. aeruginosa*
	4	3	0.7 units	
Holweck, Lacassagne (*29*)	8	1.5	16.6 kr	*Saccharomyces ellipsoidus*
	2	6.1	26.3 kr	
Wyckoff (*14*)	4	3	8.4 kr	*E. Coli*
	2.3	5.4	6.7 kr	
	1.5	8.2	4.3 kr	
	0.71	17.0	4.6 kr	
	0.56	22.0	4.2 kr	
Glocker, Langendorff, Reuss (*18*)	1.54	8.0	28 kr	*Saccharomyces ellipsoidus*
	0.56	22.0	42 kr	
Haskins, Moore (*16*)	0.33	37	100 kr	*Penicillium* spores
	0.061		200 kr	
	0.33	37	250 kr	*Lilium longifl.* pollen
	0.061	200	375 kr	
Pugsley, Eddy, Oddie (*21*)	0.88	14	2.48	*E. Coli*
	0.44	28	1.48 Relative killing rate	
	0.31	40	1	
	0.29	43	0.95	
	0.22	56	0.69	
Packard (*3*)	0.1 to 0.014	123 to 880	1 Arbitrary units 0.8	*Drosophila* eggs
Glasser (*5*)	0.06	200 kv to 20 Mev	0.78 0.70 Relative effectiveness	Acute death (mice) Hair decoloration (mice)
	0.0006		0.60	Bean growth (Chin. Mung beans)
			0.75	*Drosophila* mutations
			0.85	Bar-effect in *drosophila*
Lindenmann (*27*)	0.068 to 0.0004	180 kv to 31 Mev	2475 r 2475 r	*E. Coli*

* C. Tobias and C. A. Beam, Donner Laboratories, University of California, received a sample culture from our *P. aeruginosa* strain $1630T_1$. According to their communication, their LD-50 dose with 200-kv X-rays coincides exactly with our measurements. This indicates that we might assume the factor b as a constant for one type of bacteria.

(*33, 34*) was obtained with a 2-Mev Van de Graaff electrostatic generator, which provides X-radiation at a maximum intensity of about 1.2 Mev (filtered by 0.3 cm Au-0.2 cm brass, initial half-value layer 0.7 cm lead) (*30*).

Dose rate. The dose rate applied to the bacteria was approximately 100 r/min except for the 4-kv unit, which had a dose rate of about 9 r/min at 10 cm object-anode distance. This difference in dose rate might be open to some question.

The dose measurements for the X-radiation of 39 kv and up was made with Victoreen thimble chambers (25 r and 100 r) that were calibrated for the different wavelengths by the National Bureau of Standards. The chambers used for dose determination of 2-Mev X-rays were covered with a 3-mm-wall Lucite cap to maintain electronic equilibrium.

Results

Figure 3 shows the survival curves obtained by irradiating *E. coli* and *P. aeruginosa*. The percentage survivals is plotted as a function of the dose in kiloroentgens for X-rays of different energies. The curves were drawn by the method of least squares. The points indicate the average value of the experimental findings.

All dose measurements were corrected appropriately for backscattered radiation. The amount of the backscattered radiation was determined with 25–100 r Victoreen thimble chambers. The sensitive part of the chamber was placed on the petri dish, immersed partly in the agar (approximately 2 mm) covering the glass. These readings were compared with measurements made with no scatterer present. The amount of backscattered radiation was found to be 2% at 39 kv and about 12% at 186 kv (*35–37*). A 10% allowance was made for dosimetric inaccuracy for all X-ray energies, which is rather generous for measurements of radiation in the 200-kv range. These errors are indicated by the length of the horizontal sides of the rectangles surrounding each experimental point, while the vertical lines indicate the standard error introduced by variations in bacterial counts.

In the case of *E. Coli*, a statistically significant difference was found between all results obtained from irradiation of the objects with X-rays of various energies (4, 39, 186 kv).*

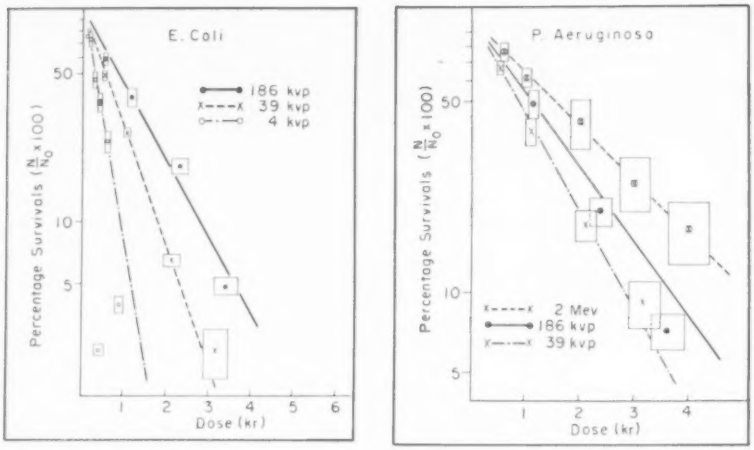

FIG. 3. Survival curves vs dose for X-rays of different energies

The irradiation of *P. aeruginosa* resulted also in a statistically secured difference between the effects of X-rays produced at 39 kv and 2 Mev. However, no significance can be ascribed to the divergence of the curves between 39 kv and 186 kv, as well as between 186 kv and 2 Mev. The different responses of these two bacterial strains seem to indicate that the biological conditions (factor *b*) have changed. Nevertheless, both experiments give evidence that there exists a definite wavelength dependency varying in its degree with the biological objects employed.

Table 2 shows the results obtained with *E. Coli* and *P. aeruginosa* irradiated with X-rays of different qualities. The relative effectiveness, *a*, was determined from the ratio of the doses needed to produce the same percentage of survivals at various X-ray energies. The effects of 186-kv radiation were chosen arbitrarily as unity. Therefore

a = (Dose at 186 kv)/(Dose at X kv)

Observations of authors carrying out similar experiments are collected in Table 1. Most of the experiments were performed in smaller energy intervals. We see from this table that most of these investigators found a decreasing effectiveness with increasing X-ray energy. Attempts to correlate the numerical findings of two different authors is, however, of no value.

Discussion

The information obtained from our experiments, as well as that gathered from other authors (Table 1), give definite evidence of a wavelength-biological effect relationship.

To demonstrate the result more clearly, the data of some of these different investigations are plotted in Fig. 4, where the quality factor *a* for different objects is represented as a function of the X-ray energy in kv.

The curves *A*, *B*, *C*, and *D* show a great similarity in their shapes. They all have in common a region of small slope at the higher energies, indicating small changes in the effectiveness of the radiation, whereas the slope becomes rapidly steeper at low energies.

Curve *A* (chromosome breaks in *Tradescantia* pollen tubes) shows similar behavior to the rest of the curves down to approximately 3 to 4 kv (*39*), where the relative effectiveness seems to be a maximum. But further decrease of voltage (increase in wavelength) seems to result in a diminution of the quality factor. There are two explanations for this observation. Either this one value reported at this low energy by this particular author was obtained by a spontaneous break of the chromosome—and not due to the radiation—or after the maximum effectiveness has been reached, more energy is released in the cell than is necessary for producing such breaks.

The curves *B* and *B′* are our experiment, carried out with *E. Coli* and

* According to personal communications by S. Goldblith, M.I.T., *E. Coli* show a 37% survival at approximately 6 to 10,000 r if irradiated with gamma rays from Co^{60} (*38*).

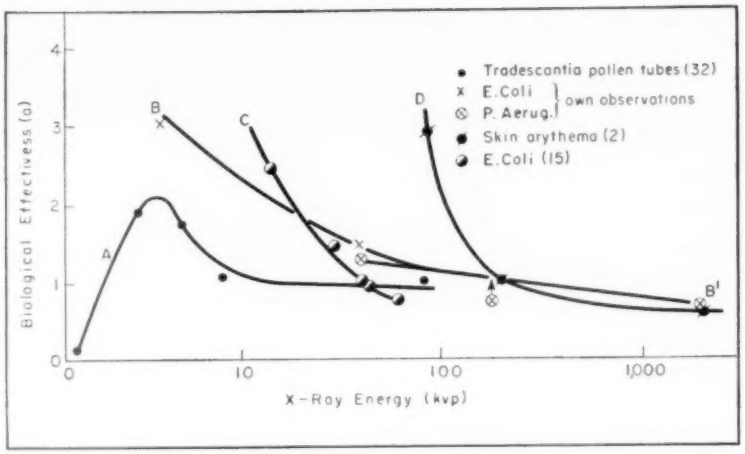

FIG. 4. Effect of X-ray energy on biological effectiveness

P. aeruginosa. Curve *C* was obtained by a different author irradiating *E. Coli* (*3, 4, 21, 39*).

Curve *D* shows the results of skin erythema measurements obtained with different X-ray energies. The measurements were made with an extrapolation ionization chamber (*2*).

Conclusions

Summarizing our own observations and experimental results obtained from others, we conclude that:

1. There is a definite dependency of the biological effectiveness of X-radiation on the wavelength.

2. This effectiveness may increase or decrease with wavelength depending on whether the irradiated biological object is affected by a small or large number of ionizations.

3. Under certain conditions and in certain objects, a small number of ionizations may be enough to cause a certain effect. Therefore, each additional ionization is biologically wasted but causes an increase in physical dose units.

4. Bacterial and other cells, as well as higher organized living material probably require a higher number of collisions to show certain (lethal) effects. These effects are consequently much more readily obtained by higher ionization densities. The biological effectiveness of the radiation decreases if absorption and ionization density become smaller.

BIBLIOGRAPHY

1. G. Failla, P. S. Henshaw. The relative biological effectiveness of X and gamma rays. *Radiology* **17,** 1 (1931)
2. G. Failla. Measurement of tissue dose in terms of the same unit for all ionizing radiations. *Radiology* **29,** 202 (1937)
3. C. Packard. The biological measurement at high voltage radiations. *Radiology* **34,** 17 (1940)
4. H. Quastler, R. Clark. Biological evaluation of 20 Mev roentgen rays. I. Acute roentgen death in mice. *Am. J. Roentgenol. Radium Therapy* **54,** 723 (1945)
5. O. Glasser in "Medical Physics," vol. 2, p. 19 (The Year Book Publishers, Inc., Chicago, 1950)
6. J. S. Laughlin. Considerations in the use of a 23-Mev medical betatron. NUCLEONICS **8,** No. 4, 5 (1951)
7. H. E. Johns. The betatron in cancer therapy. NUCLEONICS **7,** No. 10, 76 (1950)
8. J. G. Trump. Physical basis for the high skin tolerance of supervoltage X-rays. *Radiology* **50,** 649 (1948)
9. W. S. Moos, to be published
10. L. L. Haas, R. A. Harvey, J. S. Laughlin. Biological evaluation of skin effect of the 23 Mev betatron. *Am. J. Roentgenol. Radium Therapy Nuclear Med.* **68,** 644 (1952)
11. D. E. Lea, "Actions of Radiations on Living Cells" (Macmillan Co., New York, 1947)
12. G. Friedlander, J. W. Kennedy. "Introduction to Radiochemistry" (John Wiley & Sons, Inc., New York, 1949)
13. R. W. G. Wyckoff, B. J. Luyet. Effects of X-rays, cathode rays and ultraviolet light on yeast. *Radiology* **17,** 1171 (1931)
14. R. W. G. Wyckoff. Action of X-rays of various wavelengths on *Bact. coli*. *J. Expll. Med.* **52,** 769 (1930)
15. V. Hardung. Über einige strahlenbiolog. Untersuchungen mit weichen Roentgenstrahlen. *Helv. Phys. Acta* **18,** 45 (1944)
16. C. P. Haskins, C. N. Moore. The inhibition of growth in pollen and mold under X-ray and cathode ray exposure. *Radiology* **23,** 710 (1934)
17. V. V. Brunst, E. A. Sheremetieva-Brunst. Biological effects of X-rays of various wavelengths. *Am. J. Roentgenol. Radium Therapy* **63,** 90 (1950)
18. R. Glocker, H. Langendorff, A. Reuss. *Strahlentherapie* **46,** 517 (1933)
19. R. Holweck, A. Lacassagne. Schädigung von Saccharomyces ellipsoidus. *Compt. rend.* **190,** 524 (1930)
20. A. Lacassagne. Action des rayons X de grande longeur d'onde sur les microbes. Establissement de statistiques precises de la mortalité des bacteries irradiées. *Compt. rend.* **188,** 200 (1929)
21. A. T. Pugsley, T. H. Oddie, C. E. Eddy. Bacterial action of X-rays. *Proc. Roy. Soc. (London)* **B118,** 276 (1935)
22. W. S. Moos. Effects of slow cathode rays on microorganisms. NUCLEONICS **8,** No. 1, 50 (1951)
23. D. Bromley, R. H. Herz. Quantum efficiency in photographic X-ray exposures. *Proc. Phys. Soc. (London)* **B63,** 90 (1950)
24. W. V. Mayneord. Total energy absorption in biological objects. *Nature* **145A,** 972 (1940)
25. W. V. Mayneord. Energy absorption of X and gamma rays in tissue. *Brit. J. Radiol.* **13,** 235 (1940)
26. C. J. Hudson. The dependence of X-ray erythema on wavelength. *Radiology* **29,** 95 (1937)
27. J. Lindenmann. Die Roentgenschädigung von E. Coli bei 180 kev und 31 Mev. *Experientia* **9,** 22 (1953)
28. F. Holweck. Production des rayons X monochromatiques de grande longeur d'onde. Action quantique sur les microbes. *Compt. rend.* **188,** 197 (1929)
29. F. Holweck, A. Lacassagne. *Compt. rend.* **190,** 524 (1930)
30. W. S. Moos. 2 Mev X-ray and cathode ray irradiation of *P. aeruginosa*. *Experientia* **8,** 105 (1952)
31. L. S. Taylor, C. F. Stoneburner. A standard ionization chamber for grenz rays (3–12 kv). *Radiology* **23,** 22 (1934)
32. A. Mutcheller. Absorption curves and spectra of X-ray beams. *Radiology* **20,** 32 (1933)
33. J. G. Trump, R. J. Van de Graaff. Irradiation of biological materials by high energy X and cathode rays. *J. Appl. Phys.* **19,** 599 (1948)
34. C. G. Dunn, W. L. Campbell, H. Fram, A. Hutchins. Biological and photochemical effects of high energy, electrostatically produced X-ray and cathode rays. *J. Appl. Phys.* **19,** 605 (1948)
35. E. Quimby, L. D. Marinelli, J. H. Farrow. A study of backscatter. *Am. J. Roentgenol. Radium Therapy* **39,** 799 (1938)
36. H. B. Hunt. Advantages and disadvantages of small chamber measuring instruments. *Radiology* **20,** 129 (1933)
37. J. A. Victoreen. Roentgen rays: measurement of quality, in "Medical Physics," vol. 2, p. 889 (The Year Book Publishers, Inc., Chicago, 1950)
38. W. R. Dixon *et al.* Radiation measurements with the Eldorado Co^{60} Teletherapy Unit. *Brit. J. Radiol.* **25,** 314 (1952)
39. D. G. Catcheside, D. E. Lea. Effect of ionization distribution on chromosome breakage by X-rays. *J. Genet.* **45,** 186 (1943)
40. S. L. Whitcher. Energy absorption by externally irradiated liquids. NUCLEONICS **10,** No. 4, 4; No. 5, 54 (1952)
41. N. W. Timofeeff-Resovsky, K. Zimmer "Biophysik," vol. 1 (S. Hirzel Verlag, Leipzig, 1947)

TABLE 2—Biological Effectiveness of Various X-Rays

Voltage	*Dose (r)*	*Survivals* (N/N_0)	a *(relative effectiveness)*
E. coli			
4 kv	625	0.20	3.04
39 kv	1,250	0.20	1.53
186 kv	1,900	0.20	1
P. aeruginosa			
39 kv	2,000	0.20	1.3
186 kv	2,600	0.20	1
2 Mev	3,550	0.20	0.73

FIG. 1. Detector assembly for background monitor

Interpreting Background Data from Scintillation Detectors

Continuous observation of radiation background for seven months indicated that:

1 **Resolution was limited to a 15% change in background by the temperature dependence of electronic circuits used with the scintillation detectors.**

2 **Background is relatively constant except for infrequent excursions related generally to the amount of precipitation; usual variations are within the 15% resolution set by instrumentation**

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BACKGROUND generally means the radiation associated with cosmic rays and naturally radioactive substances such as radium and uranium. But the advent of nuclear fission and artificially produced radioisotopes has broadened the meaning of background.

From a practical point of view, the purposes of area background monitoring today are:

1. To detect malfunctions by observing departures from normal background in production facilities involving radioactive material, including nuclear reactors, and to assure safe dispersion of wastes and effluent.

2. To track the spatial and time distribution of increased radioactivity during weapons tests.

Since 1951, the Health and Safety Laboratory has maintained, on the roof of the NYOO, a continuously recording area monitor for measuring background and for collecting and counting atmospheric dust. A periodic perusal of the continuous records has been made since that time. After August, 1952, special attention was paid to maintaining hourly records of the area gamma background, and an attempt was made to correlate the observed background with meterological data. This report summarizes background observations for the period August, 1952 to February, 1953 and discusses, briefly, the equipment behavior.

Monitoring Equipment

The gamma background monitor consists of two channels, each with a thallium-activated sodium iodide crystal coupled to a photomultiplier tube.

Current from the multiplier tube is fed into an amplifier plus cathode-follower circuit for preamplification.* Both detectors and their preamplifiers are incorporated into a single assembly and suspended from a superstructure attached to a shack on the NYOO roof (Fig. 1). Power supplies and recording equipment are inside the shack.

A gamma-ray photon, upon interacting with the crystal by any of the usual absorption processes, (photoelectric absorption, Compton scattering, or pair production) causes light quanta produced in the crystal to liberate electrons from the photoemissive surface of the photomultiplier tube. The resulting ionization pulse is fed into a pulse amplifying network that feeds a ratemeter circuit.

Temperature Correlation

It soon became apparent that the radiation background record exhibited a negative temperature gradient with respect to the temperature reported by the U. S. Weather Bureau about 3½ miles from the equipment. That any correlation could be established from temperatures measured at a point so remote from the monitoring station may at first seem surprising. Actually, variations in temperature from one point to another in the New York City area are relatively slight.

Even though the cause of the apparent temperature correlation was unknown, it had to be considered properly in evaluating fluctuations in the background record. The procedure followed is outlined here.

Designating the background in scale divisions by B and the temperature in degrees F by T, the least squares fit to the line

$$B = a + bT \qquad (1)$$

was determined for each month with the exception of October. During that month the installation was overhauled; two gamma channels replaced the single one formerly in operation. The data, then, were divided corresponding to this modification. In Eq. 1 a and b are obtained by solving the normal equations

$$\begin{aligned} na + b\Sigma T &= \Sigma B \\ a\Sigma T + b\Sigma T^2 &= \Sigma TB \end{aligned} \qquad (2)$$

where (T,B) are a single set of hourly observations.

The standard error of estimate, E, is given by

$$E = \left\{ \frac{\Sigma B^2 - \dfrac{(\Sigma B)^2}{n} - \dfrac{\left(\Sigma BT - \dfrac{\Sigma B \Sigma T}{n}\right)^2}{\Sigma T^2 - \dfrac{(\Sigma T)^2}{n}}}{n-2} \right\}^{1/2} \qquad (3)$$

Strictly speaking, this quantity represents the standard deviation of B from the least squares fit only at the point whose abscissa is the average value of T. However, E is a good approximation to the standard deviation over the entire line, except near the ends.

For purposes of determining changes in the background that were not attributable to the temperature effect, two parallel lines are conceived as being constructed above and below $B = a +$

TABLE 1—Summary of Data

Month	*Channel*	*Regression equations*	*Temp. limits (°F)*	*Background limits*	E
Aug. 1952	1	B = 67–0.68 T	55–87	9–27	1.14
Sept. 1952	1	57–0.54 T	52–93	10–29	1.00
Oct. 1952 (first half)	1	48–0.39 T	40–78	17–33	1.84
Oct. 1952 (second half)	1	27–0.096 T	31–69	20–29	0.812
	2	30–0.11 T	31–69	23–27	0.559
Nov. 1952	1	24–0.053 T	28–70	17–27	1.48
	2	29–0.092 T	28–70	21–29	1.31
Dec. 1952	1	27–0.087 T	12–59	17–26	1.17
	2	28–0.073 T	12–59	22–28	0.858
Jan. 1953	1	22–0.15 T	21–56	13–24	1.35
	2	24–0.082 T	21–56	17–27	1.60
Feb. 1953	1	20–0.12 T	16–66	10–21	1.61
	2	24–0.10 T	16–66	15–24	1.24

*Circuitry was discussed by A. A. McKenzie, *Electronics* **25**, No. 4, 131 (June, 1952).

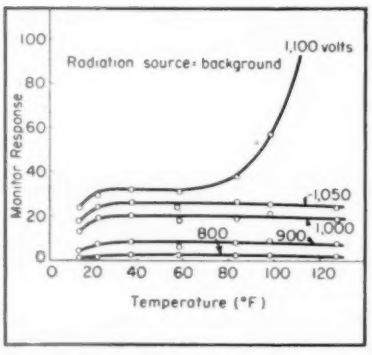

FIG. 2. Background monitor response for natural background

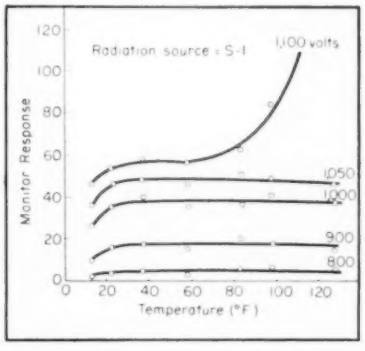

FIG. 3. Monitor response for laboratory radiation source

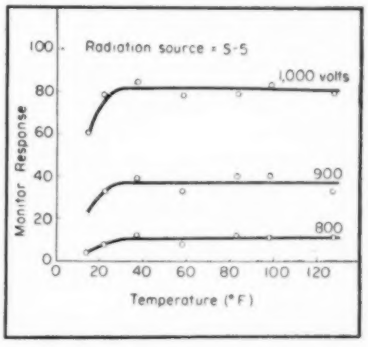

FIG. 4. Monitor response for another radiation source

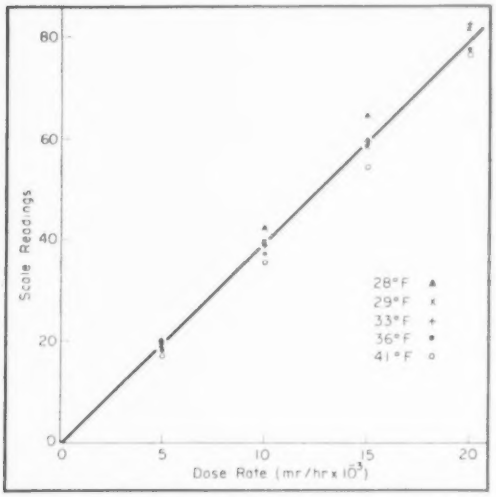

FIG. 5. Calibration curve for channel 1 of monitor

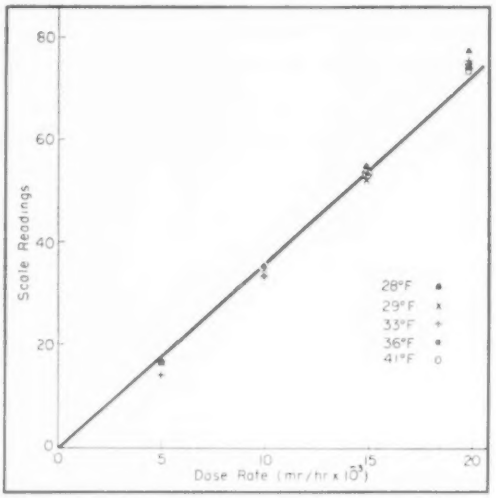

FIG. 6. Calibration curve for channel 2 of monitor

bT. These lines, each having a slope b, are drawn a distance about $2E$ from the least squares line. Twice the standard deviation corresponds closely to a 5% significance level. Periods in which points exceeded the temperature-background range established by these lines, if occurring on both channels, were recorded and probably represent real changes in the background. There were few such periods during the months covered by this report.

Table I summarizes for August, 1952 through February, 1953 the least squares fit, and the residual standard deviation for each channel.

Origin of Temperature Effect

Recently, experiments have been performed that establish the instrumental origin of the background temperature correlation. Moreover, although NaI itself has a negative temperature coefficient in the range of interest,* this is a very much smaller effect than that observed.

An experiment was set up in the Health and Safety Laboratory using equipment very nearly identical to the background monitor on the roof. The detector head was placed inside a variable-temperature oven. Gain of the system was adjusted by varying the plate voltage on the photomultiplier tube.

Three different backgrounds were used: the normal laboratory background and two higher backgrounds simulated by small Co^{60} sources in an adjacent room. Seven different temperatures were used: 14°, 22°, 37°, 58°, 83°, 98° and 127° F.

Results are shown in Figs. 2, 3 and 4. Background recorded is independent of temperature over the range at hand. The slight scatter in the points was caused, presumably, by inability to fix the multiplier-tube plate potential by better than 6 or 7 volts in about 1,000 volts.

A pronounced drop in response occurs at the lower temperatures. Thus, the head assembly exhibits, if anything, a positive coefficient at the colder end of the temperature range.

Calibrations. In retrospect, it is clear that the background monitor should have been calibrated at least once a week since the beginning of the program. Frequent calibration would have given a clue at an early date to the true nature of the apparent temperature dependence.

Calibration of the equipment was done with a 1-mg Ra source having 0.5-mm Pt filtration placed at suitable positions on the roof. Figures 5 and 6 show data taken on five consecutive days at different outside temperatures. What appears at first as simply scatter about the calibration curve turns out, in Channel 1, on closer scrutiny, to reflect a negative temperature coefficient similar to that found in the hour-by-hour data. Channel 2 also exhibits a negative coefficient, but too small to be statistically significant.

Test of temperature dependence. The instrumental origin of the background-temperature correlation was corroborated by calibrating the instrument twice on the same day and changing the temperature of the inside apparatus between calibrations by opening the door to the roof shack, permitting the temperature to drop. Both units exhibited an increased response in the afternoon, at which time the temperature was about 20° F lower inside the shack.

Figure 7 is a typical response due to a lowering of temperature. The rise in the radiation background record is apparent.

Figure 8 shows the two recording channels after a source has been brought near the equipment and then removed. Both channels show a pronounced time delay in returning to expected levels.

"Normal" Background

Periods of unusually high or low activity for August, 1952 through February, 1953 are recorded in Table 2 as fractions of the background to be expected on the basis of the regression equations in Table 1. For example, 1.20 would indicate (with an approximate 5% significance, as explained earlier) a background 20% higher than normal.

Possible explanations of these deviations are listed under "Comments." It should be noted that six of the seven periods of low background are associated with zero precipitation, while nine of the thirteen periods of high activity are associated with some rainfall. Of course, a great majority of

* W. L. Minarik, H. G. Drickamer, *Rev. Sci. Instr.* **22**, 704 (1951).

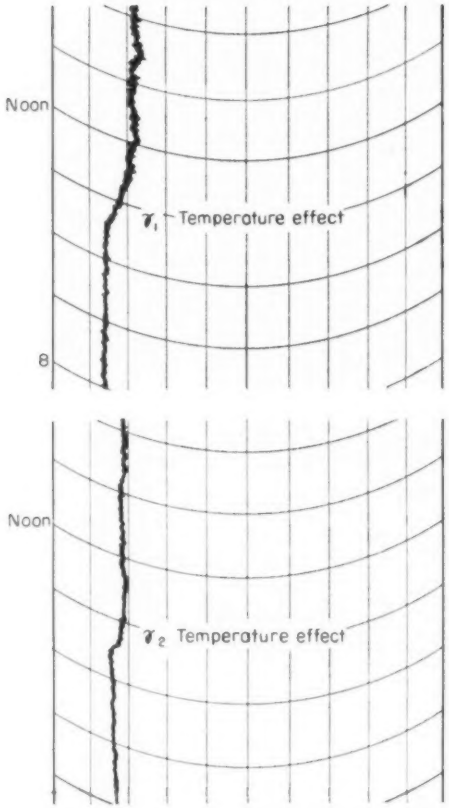

FIG. 7. Increased response obtained when environmental temperature of electronic circuits was changed

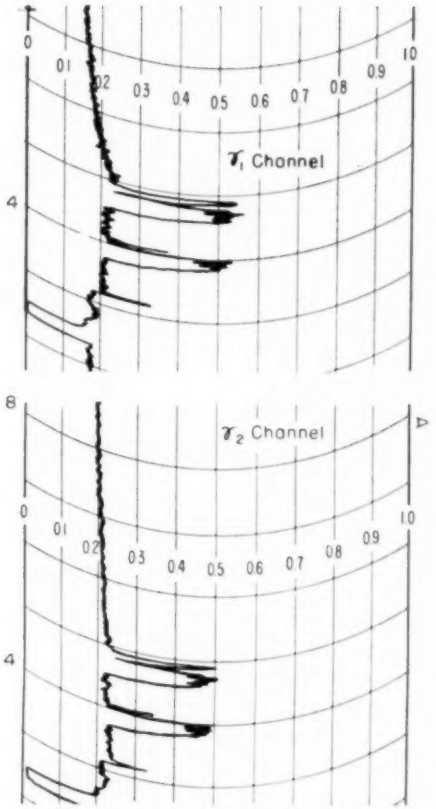

FIG. 8. Lag in background monitor response

rainfall periods had no measureable effect on the background.

Summary

Except for infrequent periods, generally associated with the presence or absence of precipitation, radiation background exhibits a substantial constancy. Since the equipment used could not definitely resolve less than a ±15% change in "normal" background, this figure is probably an upper limit to usual variations in background. Undisturbed natural background may be considerably more stable than this.

* * *

The enthusiastic interest of many of our colleagues in the Health and Safety Laboratory has encouraged us to continue actively in the work of understanding and measuring radiation background. In particular, grateful acknowledgements are made to R. Graveson and H. J. DiGiovanni, who designed the original equipment, for their continued and wholehearted cooperation in all matters pertaining to instrumentation. Professor Morris Shamos, Physics Department, New York University, made a number of valuable suggestions that are being incorporated into our work.

TABLE 2—Variation of Background

Date	*Hours*	*Times predicted background* (*Average*)	(*Min. or max.*)	*Comments*
Aug. 5	8–18	1.25	1.50	Trace precipitation
Aug. 6	7–24	1.16	1.50	2.05 in. rain, 1300–2400
Aug. 7	9–14	1.14	1.18	0.10 in. rain at 0500
Aug. 11	10, 16–17	1.20	1.27	No precipitation
Aug. 12	11–15	1.12	1.18	0.72 in. rain, 1500–2100
Aug. 21	23–24	1.10	1.10	0.45 in. rain, 1700–2400
Aug. 23	1–7	0.94	0.92	No precipitation
Aug. 27, 28	15–8	0.84	0.77	No precipitation
Aug. 28	19–23	0.91	0.88	0.01 in. rain at 1400
Sept. 4	16–19	0.88	0.82	No precipitation
Sept. 5	16–20	0.84	0.80	No precipitation
Sept. 7	4–14	0.92	0.87	No precipitation
Sept. 16	8–10	1.09	1.14	No precipitation
Sept. 17	9–11	1.08	1.10	No precipitation
Sept. 18	11–12	1.10	1.10	0.02 in. rain at 1100
Sept. 24	10–12	1.08	1.14	No precipitation
Oct. 2	19–34	1.12	1.38	0.55 in. rain, 1800–2400
Oct. 13	12–13	1.09	1.09	No precipitation
Oct. 17	2–10	0.87	0.85	No precipitation
Jan. 25	1–3	1.19	1.33	0.13 in. rain, 2400–0400

CROSS SECTIONS

Simple Radiation Shielding Doors

By W. G. WADEY
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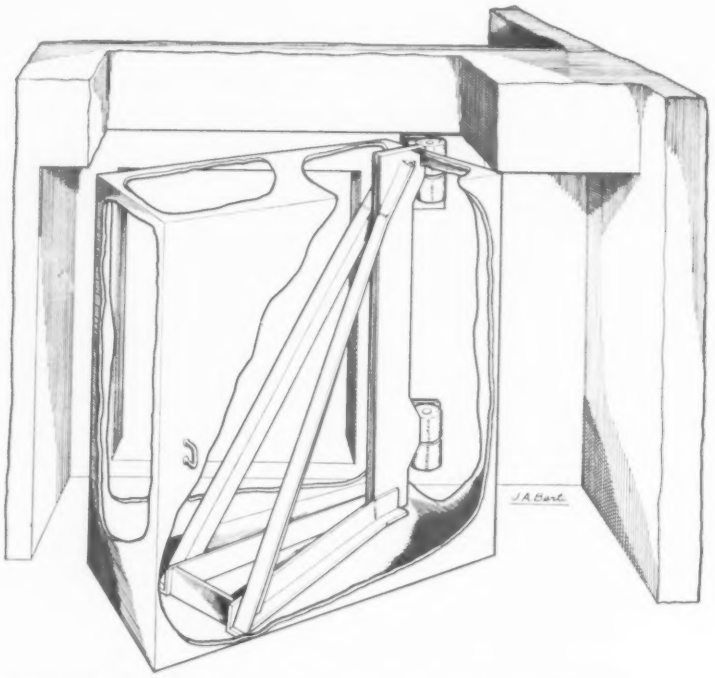
New Haven, Connecticut



SHIELDING DOOR uses commercial roller bearing hinges to support its weight

As part of the radiation shielding for the Yale linear electron accelerator, two concrete doors were required, one 2-ft thick and one 4-ft thick. The larger door is 8-ft wide, 8½-ft high, and 4-ft thick. This means a weight of about 25 tons. Except that it is 2-ft thick, the smaller door has the same dimensions; it weighs about 14 tons.

At other laboratories various designs of power-operated rolling or rising doors have been used. We wished to have a door that was as simple and foolproof as possible—one which a man could open by himself with no possibility of being trapped by loss of electric power or failure of a hydraulic mechanism.

A simply-hinged door, with no counterweights or mechanical complications, proved practicable. It uses commercial roller bearings as load-bearing hinges. The Farrel-Birmingham Company of Ansonia, Conn., designed the hinged and load-bearing gate for us.

The structure of the larger door is shown in the illustration on this page. Concrete is poured into a shell or box made of ¼-in. steel plate. This box forms the outer surfaces of the finished door. The load is borne by the gate. Its backbone is a vertical 2-in. steel plate that projects from the box and bears the moving halves of the hinge blocks. The gate itself is welded up from 6 × 4 × ⅝-in. steel angle. Before the concrete was poured, the gate was welded to the box with many pieces of reinforcing rod.

The door frame is made of 12-in. and 6-in. steel channel except for the piece to which the hinges are bolted. This is a 2-in.-thick plate and is the main load-bearing member of the frame. It is anchored to the concrete wall by a network of reinforcing rods.

Construction technique. The frame is first set in place, trued and leveled, held with timbers, and welded to the reinforcing rods. The concrete wall is then poured, but a slot or chute is left open where the top of the closed door will be. After that concrete has set, the gate is placed on the hinges and the box blocked in place around it with the door in the open position.

A welder works inside and fastens the box and gate securely together. Then the door is closed and blocked in place tight against the frame. Finally, it is filled with concrete in several pourings through the chute and the open top of the box. The wall above the door is then completed.

The finished 25-ton door is easily moved by hand. A force of 20-lb on the handle will close or open the door. If left free it will swing to a half-open position. It must be latched open or closed.

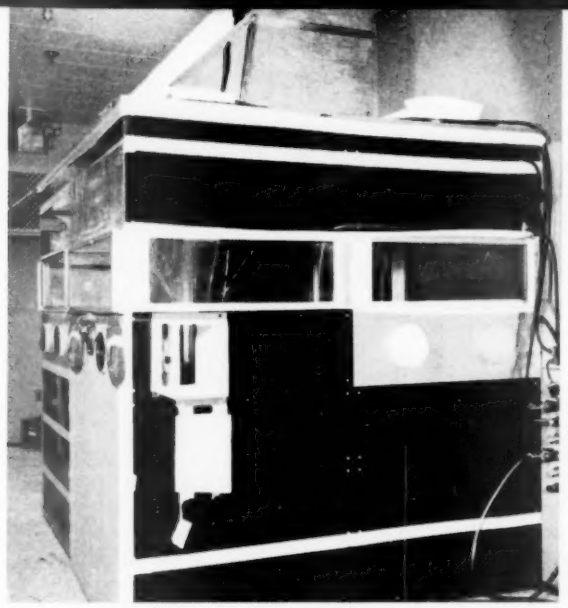
In building the smaller door here, the braces shifted as the concrete was poured around the frame. Its hinge axis is not true, and the door swings shut from all positions. Still, a force of about 20-lb is sufficient to open it.

This lack of trueness can readily be seen with a mason's level. Because of this we can now say that such doors can be set true enough without special efforts. We were not at all sure this would be so.

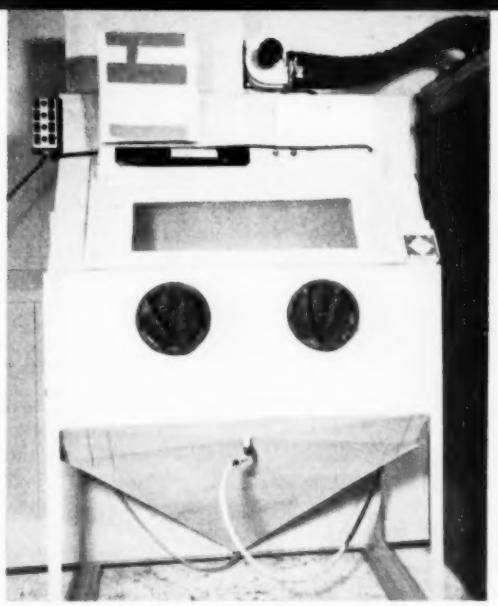
Cost. The cost of the doors cannot be determined precisely because the doors and the shielding walls were built together. However, the two doors cost about $11,500. The architects, Douglas Orr-Eero Saarinen and Associates, have informed us that the thickness of the door does not influence its cost much, so that we can say that each door cost about $6,000.

* * *

This work was assisted by the U. S. Atomic Energy Commission.



DECONTAMINATION CHAMBER is made of Panelyte sheets (St. Regis Paper Co.) mounted on aluminum angle frame over stainless-steel floor with emergency drain at its center. Panels are interchangeable with standardized gloved ports and safety-plate glass viewing windows. One work station is shielded with $\frac{1}{2}$-in. lead and X-ray glass window, has remote-control tongs. Lights and exhaust filters for 1,000 ft^3/min ventilation system are mounted on top of chamber. Sliding door is at other end of unit



SANDBLASTING in this unit gave average radiation reduction values, in a test run with items that withstood chemical decontamination, of 85% for beta-gamma radiation, 55% for alpha radiation in an average blasting time of 10 min, using 25-lb air with No. 120 Carborundum grit. Larger grits used at higher pressures give more rapid and complete decontamination, but with increased surface damage

Two Inexpensive Decontamination Units

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A versatile decontamination chamber and a sandblasting cabinet have been designed for decontamination of laboratory equipment. Construction of both units is shown by the illustrations on this page.

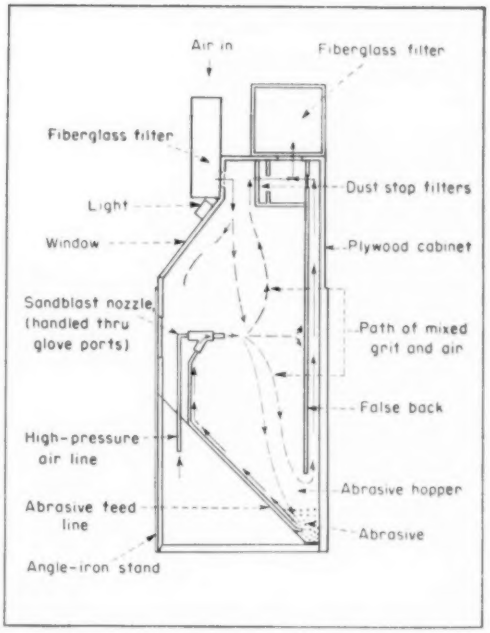
The decontamination chamber has been used successfully for manual disassembly and cleaning of equipment with radiation levels as high as 5 r/hr. Work in the chamber is performed on an inexpensive pipe and L-frame dolly equipped with a metal tank that serves as a sink for chemical decontamination. A small electric crane, operated from a hand-held control box outside the chamber, can move materials to any position within the chamber.

The air lock visible in the picture is used for transferring items into the chamber from standard gloved boxes. Larger items are introduced and removed through a sliding door. Care in removing decontaminated items keeps contaminants in the unit.

Tape is used to seal the door shut and also to seal cracks between Panelyte sheets. The interior of the chamber is coated with $\frac{1}{32}$ to $\frac{1}{16}$ in. of Monsanto D-1000 water-dispersion strip coat that can be removed when it is contaminated.

When chemical decontamination is unsuccessful, sandblasting can reduce radiation levels as much as 99%.

* Hanford is operated for the U. S. Atomic Energy Commission by the General Electric Co.



SANDBLASTING CABINET is made of plywood; heavy coat of Monsanto D-1000 strip coat on inside seals openings, makes unit dustproof. Exhaust blower and filter provide controlled airflow to prevent room contamination. Sandblast nozzle is an American Wheelabrator Equipment Co. suction gun. Grits contaminated by many months of recycling do not recontaminate cleaned surfaces, but filters have to be replaced frequently

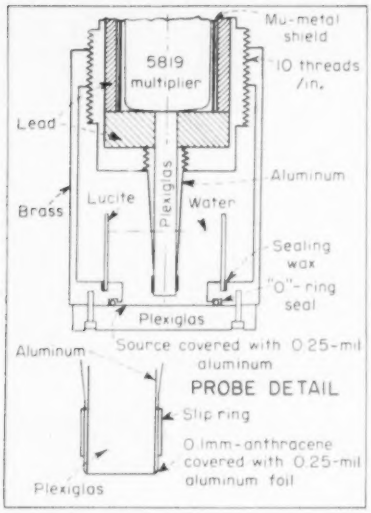


FIG. 1. Scintillation probe and arrangement for measurement

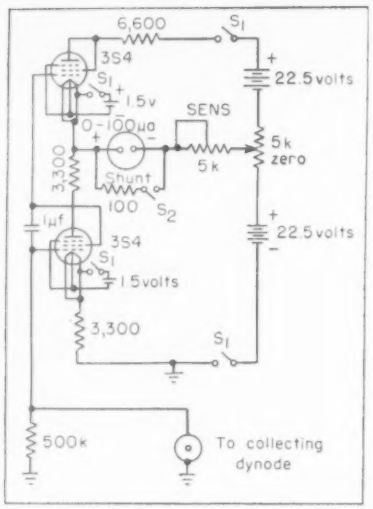


FIG. 2. D-c microammeter for measuring photomultiplier output current

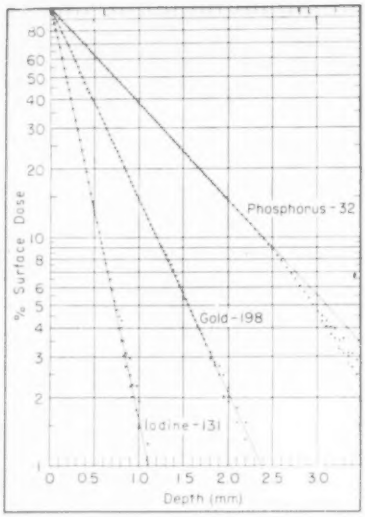


FIG. 3. Results obtained in tissue-equivalent media with three isotopes

Scintillation Probe for Determining Relative Beta-Ray Intensities

By WILLIAM B. ITTNER III* and MICHEL TER-POGOSSIAN

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Washington University Medical School
Saint Louis, Missouri

Beta-ray dosimetry, in biology, involves determination of the energy dissipated in a tissue-equivalent medium by the radiation at a particular point. Mapping of a radiation field in the immediate vicinity of a source, however, is rendered difficult by the steepness of the radiation gradient. This article describes a scintillation counter instrument designed for such use.

Absorption of medium-energy beta rays in low atomic number elements is practically independent of the atomic number and depends only on the density of the absorber. Consequently, if a beta-ray dosimeter is built with a detector of moderately low atomic number materials whose density is close to one, it can be expected to be useful for beta-ray dosimetry in a tissue-equivalent medium without disturbing the beta radiation field.

In a scintillation counter, the relation between the energy dissipated in the crystal by electrons and the intensity of the current generated in the photomultiplier tube is linear over a wide energy range (*1, 2*). On this basis it appears that a scintillation counter can be used in biological beta-ray dosimetry, provided that the crystal used is composed of low atomic number elements, and that its density is close to that of tissue.

Scintillation Counter

The present apparatus is designed to map the gradient of the radiation field in the vicinity of an extended, plane beta-ray source immersed in water. It is a scintillation counter (Fig. 1), the detecting element of which is a thin layer of anthracene crystals cemented on the plane surface of a cylindrical Lucite rod that "pipes" light generated in the crystals to a photomultiplier tube. Crystalline anthracene is used because of its high efficiency as a scintillating medium. The density of anthracene is approximately 1.25 gm/ml, a value somewhat higher than that of water, which is usually taken as a standard tissue-equivalent medium. However, because the thickness of anthracene used as a phosphor is small with respect to the range of medium-energy beta rays in water, it is assumed that the layer of anthracene does not affect appreciably the radiation field.

The technique used in depositing the anthracene on the Lucite rod is as follows: A small quantity of finely powdered anthracene crystals is mixed with an approximately equal amount of plastic cement (Casto-Gloss, Castolite Co., Woodstock, Ill.). The mulch thus obtained is ground in a mortar and then painted on the end of a machined, highly polished cylindrical Lucite rod. After drying, the film of anthracene is smoothed down with fine emery paper to a thickness of about 0.1 mm.

The end of the Lucite cylinder opposite the anthracene-covered surface is in contact with the photocathode of an RCA 5819 photomultiplier tube. This tube is surrounded by a magnetic Mu-metal shield and housed in a light-tight stainless-steel cylinder. The light-piping Lucite rod is surrounded by aluminum. The anthracene surface is covered by a light-tight aluminum foil approximately 0.006 mm thick.

Electronic circuits consist of a regulated high-voltage power supply and vacuum-tube microammeter (Fig. 2). Pulses from the photomultiplier tube are read as an integrated d-c current.

The scintillation counter is mounted in a vertical position with the probe immersed in a Lucite container filled with water. A low-pitch screw allows vertical motion of the counter probe for scanning of the radiation field of a

* Present address: International Business Machines Corp., Endicott, N. Y.

beta-ray source placed at the bottom of the container.

Results are plotted as microammeter current versus distance between the end of the probe and the surface of the source, the latter being read directly on a micrometric scale.

Instrument Limitations

The fact that only relative radiation determinations can be performed is not a significant restriction on the use of this instrument; in general, it is comparatively easy to determine theoretically the absolute radiation intensity at the source surface. For example, in the case of an infinitely-thick beta-ray source, the intensity of radiation at the surface is equal to one-half that calculated at a point within the source where energy equilibrium is reached.

The present instrument has been specifically designed for use in connection with infinitely-extended plane sources. However, sensitivity of the instrument is sufficiently high to apply it to the mapping of more complex isodose surfaces through the use of a considerably smaller detecting element.

The plane radioactive sources to be investigated must be sufficiently extended to avoid edge effects. In practice, this means that the edges of the source should not be closer to the detecting surface than the range in a tissue-equivalent medium of the beta rays emitted by the source.

The tissue equivalence of the materials surrounding the beta-ray source is probably adequate. The source is backed by a thick Lucite plate and surrounded by water. This arrangement is satisfactory. However, the light piping rod is surrounded by an aluminum shell, which, in the vicinity of the source is about 0.5 mm thick. This could conceivably introduce some distortion of the radiation field, but such distortion is assumed small.

Beta-ray distribution measurements made with this instrument are somewhat complicated when the source under investigation emits gamma rays in addition to the betas. The gamma radiation contributes to the photomultiplier current by producing pulses in the anthracene as well as in the photomultiplier tube itself. This contribution can be determined and subtracted from the total current by covering the source with an aluminum absorber sufficiently thick to stop the betas, and measuring the gamma component alone.

When a thin source emitting both gamma and beta rays is measured, the gamma contribution is usually small, and the method described for compensating for gamma-ray contribution is satisfactory. However, for thick sources, the gamma contribution becomes increasingly large with respect to that of the beta rays, leading to greater corrections and consequently to less reliable results.

Measurements

The beta radiation gradient along a direction perpendicular to an infinitely extended plane source of radiation has been determined for P^{32}, Au^{198} and I^{131}. Sources were prepared by saturating circular disks of filter paper with an aqueous solution of the isotope, in the case of P^{32} and I^{131}, and with a colloidal suspension in water, in the case of Au^{198}. The size of the filter paper disks exceeded the diameter of the probe by twice the beta-ray range in a tissue-equivalent medium.

Radioactive disks thus prepared were autoradiographed to detect any inhomogeneity in distribution of activity. Examination of the autoradiographs revealed a uniform distribution with the exception of a marked excess of activity at the outer edge of the disk. Accordingly, the disks were made somewhat larger than necessary and the outer edges trimmed to provide a uniform source. The sources thus prepared were backed by a ½-in. Lucite plate and covered with a 0.006-mm aluminum foil.

Readings were taken every 0.25 mm. The first reading corresponded to a position where the end of the probe and the surface of the source were in contact, this position being determined by measuring the electrical resistance between the aluminum foil covering the source and the probe of the counter.

The source thickness was 20 mg/cm² in all cases. Curves were also obtained for source thickness of 40 mg/cm² and 80 mg/cm². Within the experimental errors, the curves obtained with these sources were identical to those observed with 20 mg/cm² sources. For thicker sources the gamma-ray contributions of Au^{198} and I^{131} made it impossible to obtain reproducible results. An infinitely thick source of P^{32} (1 gm/cm²), however, gave a curve identical to that of the thin source.

The curves shown in Fig. 3 are nearly exponential over a considerable fraction of their lengths. This, as well as the fact that identical curves are obtained for various thicknesses of sources, can be explained on the basis of a simple theory.

If the intensity of radiation at a distance, x, in a direction perpendicular to an infinitely-thick source is assumed to be $I_\infty(x) = (I_0/2)\ \exp.\ (-\mu x)$ where I_0 is the intensity of radiation in the center of an infinitely extended source containing a uniform concentration of activity, and μ is an "effective" absorption coefficient, then the intensity of radiation from a source of thickness, s, containing the same concentration of activity, is $I_s(x) = I_\infty(x) - I_\infty(x+s)$, or $I_s(x) = (I_0/2)(1 - \exp.\ [-\mu s])\ \exp.\ ([-\mu x])$ which is proportional to $\exp.\ (-\mu x)$.

In other words, curves for any source thickness are exponential, the surface dose being less than that of an infinitely thick source by a factor $1 - \exp.\ (-\mu s)$.

In the case of P^{32}, μ, as determined from the curve on Fig. 3, is about 9.55 cm²/gm. For a source 20 mg/cm² thick, the surface dose is 8.7% of that of an infinitely-thick source containing the source concentration of activity. This result is in disagreement with the theory of Rossi and Ellis (*3*), which is based on the assumption that the beta radiation is absorbed exponentially over most of its range. This theory fails, however, to take into account the variation of energy loss as a function of the range. If it is assumed that the energy loss is roughly proportional to the range, the theory of Rossi and Ellis, thus corrected, predicts an exponential depth dose curve.

Results obtained for P^{32} are in good agreement with the experimental data of Sinclair and Blondal (*4*), who report an effective μ of 9.2 cm²/gm and a surface dose of about 9% for a source 20 mg/cm² thick. The values of μ determined from the curves of Fig. 3 are: for P^{32}, 9.55 cm²/gm; for Au^{198}, 19.2 cm²/gm; and for I^{131}, 41.4 cm²/gm.

* * *

This work was supported partially by an Atomic Energy Commission contract.

BIBLIOGRAPHY

1. J. I. Hopkins, *Rev. Sci. Instr.* **22,** 29 (1951)
2. M. Ter-Pogossian, W. B. Ittner, *Rev. Sci. Instr.* **22,** 646 (1951)
3. H. H. Rossi, R. H. Ellis, Jr., NUCLEONICS **7,** No. 1, 18 (1950)
4. W. K. Sinclair, H. Blondal, *Brit. J. Radiol.* **25,** 295 (1952)

Activation Analysis with Nuclear Emulsions

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For activation analysis involving irradiation of a sample and subsequent exposure of a nuclear emulsion to the activated sample (*1–5*), the sample must not only be capable of producing radioisotopes, but the activity must be of sufficiently long half-life. To meet these conditions (*6–18*), a method is described here whereby both sample and emulsion are exposed together to the activating radiation. Not only is half-life eliminated as a limiting factor, but, without producing a radioisotope, an element can be evaluated by any nuclear reaction recorded in the emulsion.

Two cases are considered:

1. For more precise quantitative data regarding boron metabolism, the highly ionizing alphas of the boron (n,α) reaction have been studied with Kodak NTA emulsion.

2. For application of the method to study of inactive iodine in the thyroid, the weakly ionizing betas of the $I^{127}(n,\beta)I^{128}$ reaction were studied with NTB emulsion.

For best results, the neutron flux must not be accompanied by too many γ-rays, and, to avoid excessive darkening of the emulsion, the flux must not be too dense. Tracks produced by secondary reactions, e.g., caused by emulsion components and emulsion support, must also be considered. To avoid errors in interpretation, all unknown and standard samples must be submitted to identical treatment, i.e., in exposure to the activating flux and in development of the emulsion.

Experimental Procedure

The specimen containing an unknown quantity of the element to be activated and a standard containing a known quantity of the element were exposed at the same time, together with the emulsion, to a Po-Be source.

Radiation source. The Po-Be source provides a neutron flux with few γ-rays. It is embedded in the center of a 38-cm paraffin cube, having a 10-cm-deep cavity in the middle of each of its four lateral faces (*19*).

The samples and nuclear plates, contained in black plastic boxes, were about 9 cm from the source when placed in the cavities. The neutron flux at this point, determined with In foils, was $(5.35 \pm 0.05) \times 10^3$ n/cm²/sec at the beginning of the experiment.

At first, boron specimens were exposed to the source for 10 days and iodine samples for 15 days. In the following exposures, the time was increased to compensate for source decay.

Sample preparation. Three types of samples were prepared:

1. A known amount of solution was placed on glass or Perspex slides with a micropipette—5–20 microliters for boric acid solution and 30–60 μl for iodine solutions—and the area of each drop was measured.

Although a wetting agent was used, distribution of the dried substance was not uniform due to greater crystallization around the edges of the sample. Therefore, these tests were considered as an initial approach.

2. As a check of the method in general, solution was uniformly diffused into several pairs of filter paper disks. Surface and thickness were determined so that each disk could contain the whole drop, diffused over its entire surface. The disks contained 20 μl of boric acid solution and 10–15 μl of iodine solution.

3. To simulate soft-tissue samples, salt solutions (boric acid and KI) were dissolved in gelatine. Although potassium emits betas, KI was used because of its good solubility.

The gelatine, treated by the usual formalin procedure, was embedded in wax and cut into slices—40 microns thick for the boric acid and 2 mm for the iodine samples. In each case, the slides showed some surface irregularities. For this reason, and because of the lower concentrations, the precision of these tests was lower than that of the filter-paper samples.

Emulsion analysis. Microscope readings were made with an oil objective, $\times 97$, and a calibrated reticle used with a $\times 10$ ocular. Only tracks starting from the surface were considered. The reticle field used in the calculation was 1,600 μ^2 for the boron alphas and 100 μ^2 for the iodine betas.

For background determinations, in the case of glass or Perspex samples, regions on the same slide were observed far from the drop. In the case of filter paper and gelatine, samples not containing boron and iodine solutions were exposed with nuclear emulsions. It was observed that filter paper has no effect on the background.

Boron determinations. Enriched boron (B^{10}) was used to prepare 5, 2.5, and 1% boric acid solutions. The reaction is

$$B^{10} + n \rightarrow B^{11} \rightarrow \begin{cases} Li^7 + \alpha(7\%,\ 2.794\ \text{Mev}) \\ Li^{7*} + \alpha(93\%,\ 2.316\ \text{Mev}) \end{cases}$$
$$\sigma = 3{,}500\ \text{b}$$

$$Li^{7*} \rightarrow Li^7 + 0.478\text{-Mev}\ \gamma$$

the energy being divided between the alpha and the Li recoil. The corresponding maximum range of the alphas in the emulsion was calculated to be 6μ.

Interfering tracks due to secondary reactions are caused by α's and p's from $N^{14}(n,\alpha)$ and $N^{14}(n,p)$, affecting only gelatine samples; p's giving different lengths due to n scattering against H; d recoils due to the capture reaction $H(n,\gamma)$; and elastic recoils of C, O, and N and Li recoils from the principal reaction.

The results are given in Table 1.

Iodine determinations. In the glass and filter-paper tests, a 10% alcohol solution of iodine was used; a KI solution providing 1% and 3% concentrations was used in gelatine. The reaction is

$$I^{127}(n,\gamma)I^{128},\ \sigma = 6.1\ \text{b},\ 0.43\text{-Mev}\ \gamma$$

The beta distribution of 25-min I^{128} is 7% 1.59 Mev and 93% 2.02 Mev.

Interfering beta tracks are caused by photo and Compton electrons due to γ-rays of the (n,γ) reaction. Other interfering secondary beta tracks are produced by: potassium β's and the small number of C^{14} soft β's caused by the $N^{14}(n,p)$ reaction (these two affect only gelatine samples); activated Na (this was reduced by placing samples on plastic instead of glass); and active isotopes of Ag and Br.

The specimens were kept a fraction of a millimeter away from the emulsion to record a larger number of the ends of the beta tracks. Care was also

taken in β-track counting (*20*, *21*). Before counting tracks, the total number of developed grains was counted in each reticle field; each track count was then weighted according to the probability that a row of points should be considered a track.

The background effect was very high—about half of the total effect recorded. Furthermore, the tracks per reticle field were much fewer than in the case of boron, due to the much smaller cross section. Therefore, these results are only briefly reported and given rather as preliminary data to indicate the precautions required in this case (Table 2).

Discussion

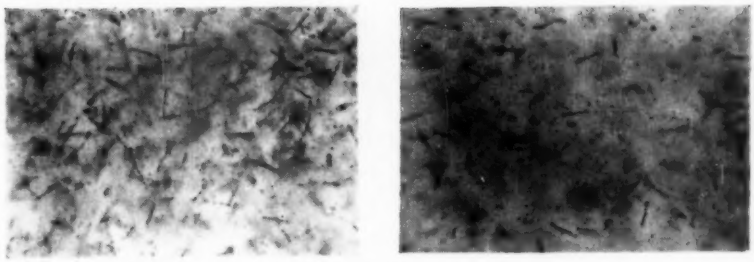
In the case of boric acid solution absorbed in filter paper, as long as the number of tracks is not too small, the accuracy attainable with a single sample can reach 3%. A comparison of samples containing equal quantities of boron, made by averaging several sets of observations, gives values of about 1.65% for 5% solutions and 6% for 2.5% solutions. In the comparison of samples with a boron concentration ratio of 2, the counting ratio was 2.18 ± 0.13. Microphotographs on this page show tracks obtained with different concentrations.

The poor precision obtainable with the gelatine samples is noticeable in the readings of single samples and in the comparison of different samples. In the comparison of samples having a boron concentration ratio of 5, the counting ratio was 4.5 ± 2.2.

Suggested improvements. This method may be improved in several ways to avoid or diminish errors.

In the case of boron, specimens having a very small boron content, e.g., 0.1% in gelatine, can be evaluated with the same precision obtainable with filter paper by increasing the product of (flux density) × (exposure time). Better results could also be obtained by improving the cutting technique to provide a smoother gelatine surface.

In the case of iodine, results can be improved by diminishing the background (avoiding glass as an emulsion support) and by determining the optimum sample-to-emulsion distance and emulsion thickness to record the greatest number of beta-track ends. Recently acquired knowledge on track differentiation leads one to expect better accounting for the background



ALPHA TRACKS obtained with different concentrations of boric acid solution absorbed in filter paper

TABLE 1—Alpha-Track Counts for Boron Samples

Boric acid concentration (%)	*Amount of solution*	*Number of counts per sample*	*α tracks per reticle field**
Drops on glass			
5	6.66 μl/cm²	24	13.77 ± 0.79
5	6.69	24	14.31 ± 1.10
5	5.20	24	11.02 ± 1.05
5	5.90	24	12.31 ± 0.95
2.5	6.50	24	7.01 ± 0.85
2.5	6.45	24	6.85 ± 0.76
1	6.65	24	3.40 ± 0.38
1	6.50	24	3.08 ± 0.36
Drops on filter paper			
5	8 μl/cm²	30	18.08 ± 0.54
5	8	30	17.93 ± 0.46
5	8	30	17.98 ± 0.51
5	8	30	17.78 ± 0.46
2.5	8	30	9.03 ± 0.51
2.5	8	30	8.58 ± 0.46
2.5	8	30	7.53 ± 0.46
2.5	8	30	7.73 ± 0.41
Solution dissolved in gelatine†			
5	40 μ thick	30	1.05 ± 0.18
5	40	30	1.09 ± 0.21
5	40	30	1.03 ± 0.17
5	40	30	0.98 ± 0.18
1	40	30	0.25 ± 0.12
1	40	30	0.21 ± 0.11
1	40	30	0.22 ± 0.11
1	40	30	0.23 ± 0.12

* Background effect was 0.10 ± 0.09 for glass, 0.12 ± 0.08 for filter paper, and 0.07 ± 0.06 for gelatine. Background is subtracted to give net track count.

† Boric acid solution was dissolved in gelatine to give the concentration of 0.5% and 0.1% in gelatine.

TABLE 2—Beta-Track Count for Iodine Samples*

Sample type	*Specimen concentration*	*Amount of specimen*	*β tracks per reticle field*	
			minimum	*maximum*
Drops on filter paper	10%	15.3–15.6 μl/cm²	0.15 ± 0.08	0.18 ± 0.08
	10%	10.2–10.4 μl/cm²	0.09 ± 0.07	0.12 ± 0.08
Solution dissolved in gelatine	1%	2 mm thick	0.10 ± 0.07	0.11 ± 0.08
	3%	2 mm thick	0.21 ± 0.11	0.28 ± 0.06

* About 24–30 fields were counted for each sample. Background was subtracted to give β-track count.

effect in the subsequent experiments.

It is also desirable, in the case of iodine, to record a sufficient number of tracks by obtaining a high enough value of the product (flux density) × (exposure time) × (cross section). In view of recent progress in emulsion techniques, it may be expected that emulsions will be prepared that can be submitted to greater (flux density) × (exposure) than at present.

In the case of histological specimens, if the tissue section is realigned on its developed autoradiograph and the margins of the areas of particular interest outlined on the film, it is possible to localize the regions where the element under consideration is more or less concentrated. This localization can be circumscribed in the case of boron alphas with an error not exceeding 4μ.

* * *

The experimental part of this research was carried out while on a Fulbright fellowship at the Medical Division, Oak Ridge Institute of Nuclear Studies, October, 1951, to March, 1952.

I express my warmest thanks to the authorities who gave me this opportunity, to Dr. Marshall Brucer, chairman, for permitting me the use of necessary equipment and for discussing the problem of degree of precision, and to Drs. R. Overman, D. Brunner and G. Boyd for their interest and very useful advice.

I also thank Dr. Boyd and Prof. Occhialini for their assistance in the preparation of this paper in 1953, bringing to my attention many important references (6–18).

BIBLIOGRAPHY

1. H. Yagoda, "Radioactive Measurements with Nuclear Emulsions" (John Wiley & Sons, Inc., New York, 1949)
2. C. A. Tobias, N. W. Dunn, *Science* **109,** 109 (1949)
3. C. Groven, J. Govaerts, G. Guében, *Nature* **141,** 916 (1938)
4. K. M. Laing, *et al.*, NUCLEONICS **9,** No. 4, 44 (1951)
5. W. E. Stephens, M. N. Lewis, *Phys. Rev.* **69,** 43 (1946)
6. C. Goodman, D. C. Picton, *Phys. Rev.* **60,** 688 (1941)
7. C. Goodman, G. A. Thompson, *Am. Mineralogist* **28,** 456 (1943)
8. E. Picciotto, M. van Styvendal, *Compt. Rend.* **232,** 855 (1951)
9. A. Ficq, *Compt. Rend.* **233,** 1684 (1951)
10. I. H. Ford, E. Picciotto, *Nuovo Cimento* **9,** 141 (1952)
11. J. W. Bremner, *Proc. Phys. Soc. (London)* **64,** 25 (1951)
12. I. Curie, H. Faraggi, *Compt. Rend.* **232,** 959 (1951)
13. J. P. Longchamp, *J. Phys. Radium* **13,** 333 (1952)
14. P. Cuer, J. P. Longchamp, *Compt. Rend.* **232,** 1824 (1951)
15. H. Faraggi, A. Kohn, J. Doumers, *Compt. Rend.* **235,** 714 (1952)
16. M. Hillert, *Research* **5,** 192 (1951); *Nature* **168,** 39 (1951); *Metal Treatment and Drop Forging* **19,** 135 (1952)
17. G. W. Stevens, *Nature* **162,** 526 (1948)
18. N. Rabinovics, *Proc. Phys. Soc. (London)* **66A,** 939 (1951)
19. G. Mayr, D. Bruner, M. Brucer, NUCLEONICS **11,** No. 10, 21 (1953)
20. R. M. Herz, *Phys. Rev.* **75,** 478 (1949)
21. A. Bonetti, Application of nuclear emulsions in the measure of β-rays spectra, Centre de Phys. Nucl. Bruxelles (1950)

Isotope Capsule for Pneumatically Operated Calibration Facilities

By BASIL MARKOW and WILLIAM GALLAS

Signal Corps Engineering Laboratories
Fort Monmouth, New Jersey

Installations engaged in design, manufacture, or use of radiation detection instruments generally require a calibrated Co^{60} or radium source. Co^{60} is ideal for calibration work; it is inexpensive and can be obtained in almost any specific activity. Its half-life, 5.3 years, makes monthly corrections for decay sufficient. The source is usually kept in a lead container and is moved either mechanically or pneumatically to the exposing position.

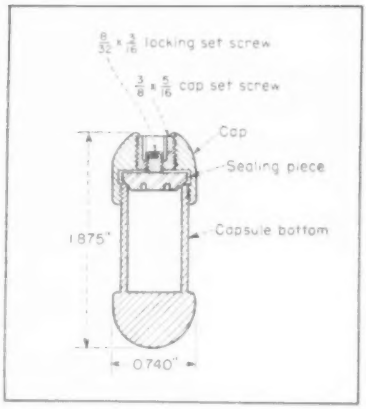
If a collimated beam is desirable, the isotope capsule is kept within the lead container and moved to a position next to a collimating aperture. The small excursion needed can be realized by using a flexible cable or air pressure.

A collimated system is not suitable for calibrating dosimeters since the size of the beam limits the number of dosimeters that can be exposed at one time. A free air source is required.

One means of moving an isotope into such a source position is a pneumatic system. Lead containers are designed so that the isotope capsule can be blown up through an aluminum tube with air pressure. The air line can be as long as is necessary for the safety of the operator. Transit time is only a fraction of a second and for most applications can be ignored.

The main disadvantage of a pneumatic system has been contamination. Capsules containing Co^{60} loosen under repeated impact, and the cobalt, which flakes easily, escapes into the aluminum tube. This constitutes a personnel hazard, and many installations using free air sources are seriously thinking of replacing the more desirable pneumatic systems with mechanical devices.

Essentially, the objection to the pneumatic system lies in the capsule design. In designing a new capsule, consideration must be given to the fact that these capsules must be remotely loaded and unloaded. To prevent the Co^{60} flakes from escaping from the capsule, the cover must make a gas-tight seal with the capsule proper. This seal must be maintained after a large number of impacts, comparable in force to those sustained by the capsule when it hits the top of the aluminum tube. It is believed that all these requirements are met by the capsule design shown in the illustration on this page.



CAPSULE for Co^{60} calibration sources incorporates high-pressure seal

The cap is a single unit made up of the cap proper and the sealing piece. The sealing piece is threaded so that it can be screwed past the inside threads of the cap proper to a position where it is free to turn to make a positive seal. The inside threads of the cap proper prevent the sealing piece from falling out when the cap is removed from the capsule.

The sealing piece is an aluminum taper that seats on the inner rim of the capsule bottom. This type of seal was used successfully in a high-pressure bomb, with pressures up to 2,000 lb/in². The capsule seal was tested at 100 lb/in² after repeated impacts without any evidence of leakage.

In loading and unloading, the bottom of the capsule is locked in a vise at an angle of about 45 degrees with the horizontal and tilted towards a barrier. The Co^{60} is then loaded and the cap placed in position with a pair of tongs from behind the lead barrier. The cap proper is tightened with a $\frac{3}{8}$-in. Allen wrench for set screws and locked by tightening the locking set screw, which is in the center of the $\frac{3}{8}$-in. Allen set screw. Both Allen wrenches are mounted on extensions for use behind a barrier.

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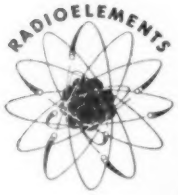

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NUCLEAR ENGINEERING

Energy Released Per Fission in the Bulk Shielding Reactor

By J. L. MEEM
Oak Ridge National Laboratory
Oak Ridge, Tennessee

THE ENERGY RELEASED per fission, E_t, is given by

$$E_t = E_K + E_\beta + E_\gamma + E_n + E_\gamma^*$$

where E_K is the kinetic energy of the fission fragments, $E_\beta + E_\gamma$ is their decay energy (not including neutrino energy), E_n is the kinetic energy of the fission neutrons, and E_γ^* is the prompt gamma-ray energy. In the past, the most reliable value for E_t has been obtained by adding the experimentally determined values of the various components.

The energy released per fission in a reactor also includes an additional component, E_c, which is the energy liberated in capture processes not leading to fission, viz., nonproductive capture in U^{235}, capture in moderator, capture in reactor structure, etc.

Accordingly, a measurement in a reactor gives E_t', where

$$E_t' = E_t + E_c$$

Since the parasitic capture term, E_c, can be calculated easily in a thermal reactor, a measurement of E_t' would give the value of E_t, the energy released per fission.

The Bulk Shielding Reactor (or Swimming Pool Reactor) has been described by Breazeale (*1*). For this experiment, a special fuel element was constructed and placed in the reactor in a position to minimize the net flow of heat and radiation into or out of the element.

The special element had a removable center fuel plate from which 1¼-in.-diameter disks were punched to facilitate activation measurement after exposure in the reactor. A similar uranium-bearing disk was activated by exposure in a known neutron flux. By comparison, the actual fission rate in the special fuel element was determined.

The special element was equipped with water tubes at top and bottom through which water was pumped at a known rate. Thermocouples were used to measure the temperature rise across the fuel element. Special precautions were taken to prevent heat leakage. The power, or rate of energy production, was determined from the water flow and temperature rise. Comparison with the fission rate gave the heat released per fission in the special fuel element. The net amount of radiation leaking out of the fuel element (less than 0.2%) was calculated as a correction to this figure.

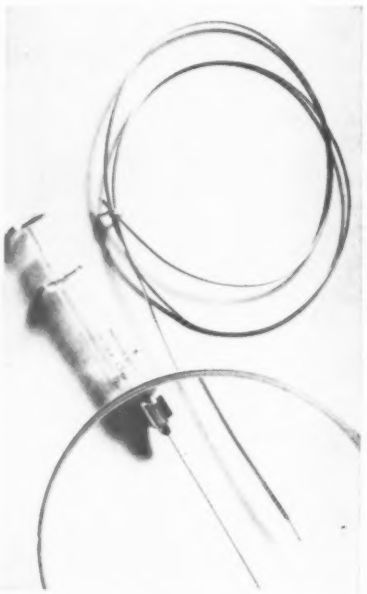
The energy per fission in the reactor, E_t', was 193 ± 5 Mev. The parasitic capture, E_c, in the Bulk Shielding Reactor was calculated to be 2.7 Mev. Accordingly, the energy released per fission (exclusive of neutrino energy) was 190 ± 5 Mev.

The energy-per-fission value is based on a gold cross section of 95 barns and a fission cross section of 549 barns for 2,200-m/sec neutrons. If these values are revised at some future date, the new value can be calculated from

$$E_t = 190 \times \frac{\sigma_{Au}}{95} \times \frac{549}{\sigma_f}$$

* * *

Detailed information on this experiment is available (2).



SMALL FLEXIBLE THERMOCOUPLE for measuring internal temperatures of operating fuel elements was developed at Argonne National Laboratory. Comparable in size to a standard hypodermic needle, unit consists of Inconel tube that serves both as outer container and one of junction metals. A 20-ft length of 0.015-in. constantan wire is drawn inside 0.040-in. tube, fused, and then one end of the tube sealed. Rugged unit has been operated up to 1,250° F

CIRCLET on nose of long-handled pair of pliers (left) expands for underwater removal of worn gaskets from radioactive processing equipment in separations section at Hanford Engineering Works. Extension handles are used by operators (right) to expand and contract circlet

BIBLIOGRAPHY

1. W. M. Breazeale, NUCLEONICS **10**, No. 11, 56 (1952)
2. J. L. Meem, L. B. Holland, G. M. McCammon, ORNL-1537 (1954)

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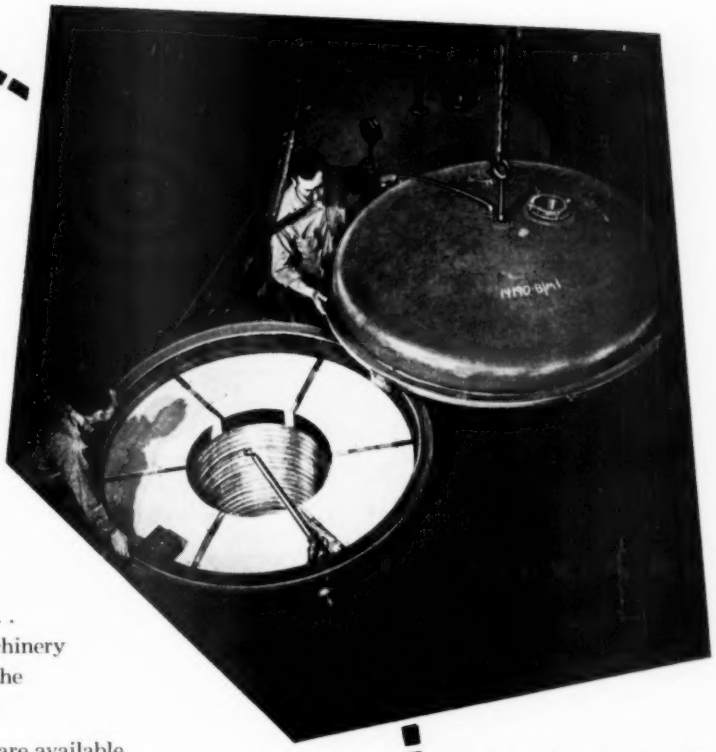

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BOOKS

Progress in Cosmic Ray Physics, Vol. 2

Edited by J. G. WILSON (Interscience Publishers, Inc., New York, and North-Holland Publishing Co., Amsterdam, 1954, xi + 322 pages, $8.50). Reviewed by GEORGE T. REYNOLDS, Palmer Physical Laboratory, Princeton University, Princeton, New Jersey.

The second volume of this "Progress" series contains five subsections treating the following subjects: (1) *Nuclear Interactions of Stopped μ-Mesons*, by R. D. Sard, Washington University; (2) *Experimental Data on the Heavy Unstable Particles*, by J. G. Wilson, University of Leeds; (3) *The Penetrating Component of Cosmic Radiation in the Upper Atmosphere*, by E. G. Dymond; (4) *The Development of a Nucleon Cascade*, by H. Messel, University of Sydney; (5) *Particle Identification with Photographic Emulsions, and Related Problems*, by L. Voyvodic, National Research Council of Canada, Ottawa.

As a unit, the book strikes a good compromise between being self-contained and depending upon the earlier volume. There are many references, mainly restricted to the period before 1953, but including some of that year. As is to be expected in this field, the book is already out of date in its treatment of certain topics, and even notes added in proof do not include some significant developments of spring and early summer of 1953. This is probably the last volume of the series that will be free of the necessity of including results obtained by use of laboratory accelerators in the discussion of particle production and interaction. One may also hope that a future volume will include discussions of the origins of cosmic rays, a topic that is by-passed in the present work.

Parts 2, 3, and 5 are reasonably complete review treatments, whereas Part 4 is restricted to a particular aspect of its topic. In Part 1, (μ-meson capture), the experimental results of μ-meson capture work are well summarized for emulsion, cloud chamber and electronic counting techniques. There is also a nondetailed discussion of the theory with useful references through 1952. The discussion of the detection of neutrons emitted from nuclei capturing μ-mesons goes into considerably more detail than is consistent with the remainder of the treatment, and the detailed relation of this work to other work is not stressed.

Part 2 (unstable particles) suffers most from the rapid developments of recent months, but this is hardly the fault of the editor. The K-meson phenomenology is no longer believed to be as stated, and knowledge of the V_2^0 (now indicated by θ^0) has advanced very significantly beyond the interpretations given in the book. In spite of the fact that drastic revisions are very likely necessary in the interpretations found here (and these necessary revisions are far from complete or certain at the time of writing this review!), the style of the presentation of the limited results may well be referred to for proper perspective for future treatments.

Part 3 (penetrating component in the upper atmosphere) is a good review of experiments analyzed through 1952. Although the evidence in this field has become somewhat clearer in recent months, this part of the book serves as a useful starting point for present studies. The main revisions in the experimental results will be concerned with observations between latitudes 52° N and 69° N. The value of this section would have been considerably increased if some results of theoretical (phenomenological) nucleonic cascade studies had been included in a form suitable for experimental interpretation. This is particularly so since these studies are not discussed in their logical place, namely Part 4.

Part 4 (nucleonic cascade) is not a review article but is restricted mainly to the work of Messel, already familiar through numerous publications. The discussion is mathematical, being developed on the basis of the initial assumption of homogeneous cross sections. As far as the reviewer can determine, the results are not left in a form well suited for experimental comparison, and no physical arguments are apparent at critical points. The section omits any useful discussion of the phenomenological treatments of the nuclear cascades.

Part 5 (photographic emulsions) affords a very useful review of methods of particle identification in photographic emulsions, together with a useful compilation of relationships between range, mass, scattering, energy loss, etc. Emphasis is fortunately placed upon utility and this section, along with its references, will be very useful to workers starting in this field. It is very unfortunate that the publication date just precluded the possibility of a discussion of the stripped-emulsion technique.

Volume 2 is not as useful nor as complete for its time as was Volume 1 of this series. However, for those parts that are reasonably up to date, for those discussions that are basic, and for the extensive bibliography, the book is a highly desirable addition to a cosmic-ray library.

Nuclear Theory

By ROBERT G. SACHS (Addison-Wesley Publishing Co., Inc., Cambridge, Mass., 1953, xi + 383 pages, $7.50). Reviewed by J. B. FRENCH, University of Rochester, Rochester, New York.

In his preface, the author expresses the hope that, despite certain gaps that have resulted from the need of keeping the length of the book within bounds, the reader will be able to "sense the spirit and learn the basic methods of theoretical nuclear physics." It is the reviewer's opinion that this goal is well attained.

The book is divided into three sections. The first devotes about 25 pages to the elementary properties of the neutron and proton and to a useful qualitative consideration of the gross features of the nucleon-nucleon interaction. The second part devotes 150 pages to the nuclear two-body problem and supplies perhaps the best review of this subject that has appeared. A chapter on the ground state of the deuteron considers, besides the usual square-well model with central forces, a variational-iteration procedure, which is applied in detail to the Yukawa well. A detailed discussion of the deuteron with tensor forces is given, and the magnetic moment and electric quadrupole moment are examined. A chapter on the continuum states of the n-p system concerns itself with the question of excited states of the deuteron and low-energy n-p scattering, both with particular potentials and more generally with the effective range theory. An instructive feature is a discussion of space exchange interactions and their connection with classical forces and with exchange currents. A chapter on slow-neutron scattering by bound nuclei examines, among other things, the chemical binding effect, the scattering of neutrons by ortho- and para-hydro-

gen, and the coherent scattering by crystals.

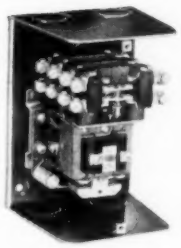
Examination of the two-body problem is completed by a long chapter that treats n-p scattering at higher energies, p-p scattering and, in considerable detail, the deuteron photodisintegration and its inverse. This chapter ends with a useful summary of the two-body problem. Part 2 of the book ends with a short chapter on the meson theory of nuclear forces (which, according to this reviewer's taste, could have been omitted).

The third part of the book devotes a chapter each to the structure of complex nuclei, electromagnetic interactions with nuclei, the theory of nuclear reactions and the theory of β-decay, about 180 pages in all.

The first chapter of this section considers first the theory of the three-nucleon system and then the Wigner supermultiplet theory. A fairly detailed treatment of the independent particle model is given for both of the extreme coupling schemes. The arguments here are in large part qualitative but are reinforced by a listing and discussion of the L-S coupling matrix element for the p-shell, as given by Feenberg and Wigner. There is also a useful examination of the relation between the L-S and j-j schemes, as demonstrated by considering wave functions for Li^6. A particularly lucid discussion is given of the saturation conditions in complex nuclei and there is a brief treatment of some properties of excited states. This reviewer would have liked a somewhat more systematic treatment of angular momentum coupling schemes with at least some mention of intermediate coupling theory, which is becoming increasingly more important. A discussion of the symmetry properties of many particle systems would have been very helpful, too (and in fact would have eliminated a couple of minor errors in the treatment of the three-nucleon problem).

The chapter on electromagnetic interactions gives an account of the theory of multiple radiation and an excellent discussion of Siegert's Theorem and, in general, of the effects due to exchange currents. Particularly valuable is a discussion of the information that one can hope to deduce from a study of nuclear magnetic moments and of isomeric transitions.

The main part of the chapter on nuclear reactions concerns itself with the dispersion theory of Wigner, Eisenbud and Teichman. This chapter is not



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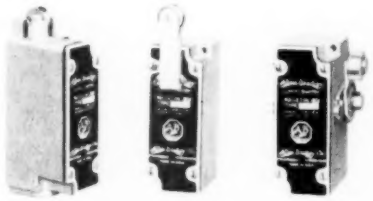

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at all easy reading (it could not be!); the reader who is accustomed to the more schematic treatment of Feshbach, Weisskopf and their coworkers will find it extremely valuable, but the reader who comes to the subject for the first time will be well advised to read it in conjunction with a more elementary treatment. It seems to this reviewer that after the basic theory is produced, not enough is done with it; there is little discussion of actual experimental cases. The other topics of this chapter are alpha radioactivity, a brief account of selection rules and a rather casual treatment of Butler's theory of deuteron reactions.

The final chapter, on β-decay, limits itself to allowed transitions but includes a good qualitative discussion of the modifications necessary for forbidden transitions. Once again, as in the chapter on electromagnetic transitions, the theory is treated as a tool by which nuclear structure may be examined. A nice treatment of favored transitions is given and some important examples are discussed. Several useful appendices are given, including one on the behavior of systems under time reversal.

One of the striking features of the book is the skill with which the author has tied together the topics considered in the first half to give a coherent picture of the nucleon-nucleon interaction and in the second half to do the same for nuclear coupling schemes and nuclear structure in general. This reviewer hopes that a second edition of the book will see the section on complex nuclei expanded considerably so that more reference can be made to experiments and some topics discussed in greater detail.

Atomic Medicine

(Edited by CHARLES F. BEHRENS, Williams and Wilkens Co., Baltimore, 1953, xiv + 632 pages $11.00). Reviewed by H. D. BRUNER, Department of Physiology, Emory University, Georgia.

This is a revised second edition of a book whose first edition received a qualified review in this journal (NU, June '50, p. 70). Regrettably that opinion must be repeated.

A collection of chapters by twenty contributors, the volume naturally possesses a range of styles and methods of presentation. The range of variation, however, is possibly too wide to make for easy and pleasurable reading. Many of the chapters are brilliant in both style and content, but others are folksy or uninspired; at least one is cryptic and one bombastic. This opinion was reaffirmed on second and third readings at intervals of a month.

The editor, as was noted in the preface, purposely refrained from pruning material that was repeated in the overlap of the different chapters. This, it is submitted, was a mistake; a tighter job of editing would have contributed to the over-all readability. At least there should have been consistency in the use of symbols. Also, a more detailed index would improve its usefulness.

The book is directed primarily to physicians with the idea of acquainting them with the medical problems created by modern nuclear physics and providing the basic physics and terminology required for awakening an interest. In this respect, it is unique and on the whole succeeds in its intent, but attention should be called to the too numerous typographical and/or factual errors that can get the novice in trouble; these errors should have been caught in proof.

A special effort was obviously made to bring all the material up to date. Certain of the descriptions are unusually complete, and the references attached to each chapter are well selected.

Accordingly, it is impossible to pass a simple judgment on the book. Quite clearly, improvements are possible, but where so many contributors are involved probably no two reviewers could agree on where the improvement should be made.

BOOKS RECEIVED

Instrumental Analysis, by John H. Harley and Stephen E. Wiberley, John Wiley and Sons, Inc., New York, 1954, vii + 440 pages, $6.50. *(To be reviewed.)*

Zirconium, Metallurgy of the Rarer Metals, No. 2, by G. L. Miller, Academic Press, Inc., New York, 1954, xviii + 382 pages, $7.50. *(To be reviewed.)*

Matter Energy Mechanics, by Jakob Mandelker, Philosophical Library, New York, 1954, xi + 73 pages, $3.75. In this book, the completed proof is presented for the author's concept of a relativistic mechanics based on a kinetic energy formula first introduced by him in 1949. Behind the derivation is the fact that, since mass increases with velocity, in this case the kinetic energy must remain smaller than the work performed.

Introduction to Nuclear Engineering, by R. L. Murray, Prentice-Hall, Inc., New York, 1954, xiii + 418 pages, $9.35. *(To be reviewed.)*

Applied Electronics, 2nd ed., by Truman S. Gray, John Wiley and Sons, Inc., New York, 1954, xxviii + 881 pages, $9.00. Part of the Principles of Electrical Engineering Series, this revision includes the discussion of fundamental principles of the original edition together with a new section on semiconductor devices.

The Collected Papers of Peter J. W. Debye, Interscience Publishers, Inc., New York, 1954, xxi + 700 pages, $9.50. Introduced with a biography by Raymond M. Fuoss, this collection consists of papers selected by Prof. Debye. Papers originally published in German and Dutch have been translated into English. They are grouped in the sections: *X-Ray Scattering, Electrolytes, Dipole Moments, Light Scattering,* and *Miscellaneous.*

Tables of Circular and Hyperbolic Sines and Cosines for Radian Arguments, National Bureau of Standards Applied Mathematics Series 36, 407 pages, $3.00 (order from Government Printing Office, Washington 25, D. C.). This book is a reissue of Table 3. It contains $\sin x$, $\cos x$, $\sinh x$, and $\cosh x$, $x = 0(0.0001)1.9999$, $9D$; $\sinh x$ and $\cosh x$, $x = 0(0.1)10$, $9D$; a conversion table of degrees, minutes, seconds to radians, and a table of multiples of $\pi/2$.

1953 Annual Report of the Federal Civil Defense Administration. Included in this report are a consideration of the threat of atomic weapons, progress in local civil defense, funds and operation, planning and research, manpower requirements, and transportation. *Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., $0.55.*

Atomic Power Symposium. This 200-page report contains 15 papers presented at the symposium held at Chalk River, September, 1953. The papers were written by staff members of AECL, Shawinigan Water and Power Co., and the Hydro-Electric Power Commission of Ontario. Subjects discussed are: reactor design, reactor control, fission product disposal and use, materials, gas and liquid coolants, and power growth and re-

sources of Canada. *Atomic Energy of Canada Ltd., Scientific Documents Office, Chalk River, Ontario, Canada, $2.00.*

ALSO OF NOTE

Recommendations for the Disposal of Carbon-14 Wastes (NBS Handbook 53). This 14-page pamphlet contains recommendations prepared by the National Committee on Radiation Protection, Subcommittee on Waste Disposal and Decontamination. Recommendations are divided into six sections: isotopic dilution, sewers, incineration, atmospheric dilution, garbage, and burial. *Government Printing Office, Washington 25, D. C., $0.15.*

Atomic Energy in Industry. This 264-page transcript of the Second Annual Conference on Atomic Energy in Industry (Jan. '54) conducted by the National Industrial Conference Board contains a discussion on industrial uses of atomic energy. Included are papers on the second decade of atomic energy, by W. Sterling Cole and George M. Dadsby, and development of commercial atomic power in Great Britain, by Sir Christopher Hinton. Conference round tables were: changing the atomic energy act; possible economic impact of atomic energy; analyses of company-group feasibility studies; reactor design and developments in fuels, metals, and coolants; and industrial use of radioisotopes. *Joseph J. Brady, Assistant Director, Public Information Dept., National Industrial Conference Board, Inc., 247 Park Ave., New York 17, N. Y.*

Selling to AEC. This pamphlet, superseding "U. S. AEC Contracting and Purchasing Offices and Types of Commodities Purchased," describes AEC's organization and procurement program, provides directory of purchasing offices, and lists products purchased. Appendices include principal construction contractors, principal architect-engineers, and bidder's mailing list application. *Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., $0.25.*

Magnetic Fields of Cylindrical and Annular Coils (NBS Applied Mathematics Series 38). This booklet gives the axial and radial components of the magnetic field at any point in space of a cylindrical or an annular coil carrying an electric current. *Government Printing Office, Washington 25, D. C., $0.25.*

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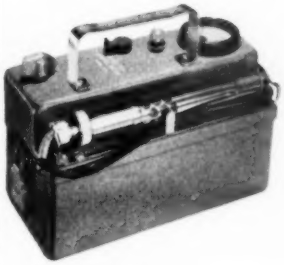

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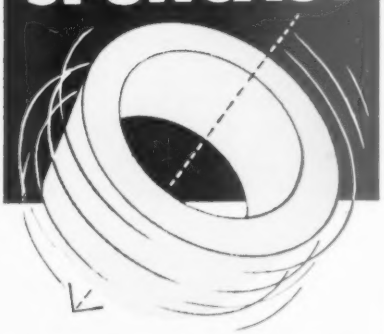

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LETTERS

What is the Recovery Factor in Spleen?

DEAR SIR:

The admirable article by Howard and Ebert entitled "Current Research in Radiobiology" (NU, Dec. '53, p. 18), contained one important error. Under the heading "Recovery: Tissues and Extracts" it is stated that extracts of spleen had been found effective in aiding recovery from damage by radiation. To the best of our knowledge this is not so.

Jacobson *et al.* reported that mice that had received an otherwise lethal dose of X-radiation, could be saved by implanting into their peritoneal cavities spleens from young or preferably infant mice (*1*). These workers tended to favor the hypothesis that this was owing to a chemical or humoral effect of the normal spleen rather than a vital effect due to survival of the transferred cells (*2*).

The following significant facts since have emerged: The spleen does not have to be intact; it is equally effective when homogenized (*3, 4*). Moreover, the homogenate is more effective when given intravenously than intraperitoneally. Other tissues besides spleen are effective: bone marrow in guinea pigs (*5*) and mice (*3*), and thymus in mice.

These findings are compatible with either hypothesis—the humoral and the vital. To eliminate the latter it must be shown that preparations without living cells are active. Hilfinger *et al.* (*6*) report that an emulsion of marrow saved irradiated rabbits and that the supernatant of such an emulsion was almost equally good. There was no proof, however, that the supernatant was cell-free and the claim must be tabled until confirmed. Lorenz and his colleagues (*7*) maintain that some heterologous material gave positive results in their hands. One cannot presume that heterospecific (i.e., guinea pig to mouse) cellular material would survive in the host; even homospecific (i.e. mouse to mouse) cells are unlikely to survive unless genetically and antigenically very similar to those of the recipient. Therefore, this indirect method of approach suggested that cells that were doomed to die were potent, presumably in virtue of their supplying a chemical not a vital factor.

Table 1—Survivors of 950 r after Injection of Spleen

No. of spleen equivalents	*Fraction of survivors*
4	17/25
2	6/6
1	24/29
1/2	12/14
1/5	5/5
1/10	10/10
1/20	3/15

TABLE 2—Survival after 950 r

Survival of saline treated control (fraction)	*Treatment of donated spleens*	*Survival fraction for no. of spleens injected* 1/2	1	4
0/16	1% formalin for 30 min	...	0/6	0/5
0/10	Stored for 2 days at 4° C	...	0/9	0/3
0/5	Stored for 2 days at −15° C	0/5	...	...
	Irradiated *in vivo* at			
0/5	2,000 r	...	0/8	...
0/5	200 r	...	0/5	...
	50 r	...	5/5	...
0/5	25 r	...	3/5	...

TABLE 3—Survival after 950 r; Antigenic Study

Survival of saline injected control (fraction)	*Injected material*	*Survival of CBA (fraction)* "Nonimmune"	*Immune*
0/13	Homologous, 1/2 CBA spleen	12/14	6/6
0/16	Heterologous, 1 A spleen	9/16	0/10

Our own work has been directed in similar directions. When as previously reported we were unable to find an active extract of homogenate of spleen, we turned to methods that would be lethal or near lethal to cells as living entities and yet be as undamaging to the chemical constituents as possible. These methods are chemical, physical and radiological.

As before, the standard test animal has been the adult mouse of the inbred CBA strain. A whole-body X-ray dose of 950 r has been invariably lethal within 30 days to the 225 mice in batches that have been used as controls to each experiment.

The "therapeutic" material has in each case been homogenized spleen from infant mice about 4 to 7 days old. In our hands the intravenous injection of the equivalent of four spleens is frequently immediately fatal, presumably from embolism. However, those that survive the injection do not seem to have a better chance of survival than those given, within limits, smaller doses. See Table 1.

One spleen-equivalent contains about 5.4×10^7 cells or cell nuclei as counted in a haemocytometer chamber. Therefore a minimal effective dose is of the order 10^6.

Chemical treatment of donated material. The homogenate was treated with formalin to give a final concentration of 0.4% formaldehyde.

Physical treatment. The homogenate was stored for 2 days in a cold room at 4° C or in a deep-freeze cabinet at −15° C.

Radiological treatment. The infant mice that donated the spleens were X-rayed immediately before sacrifice with 2,000, 200, 50 and 25 r. From histological studies it is to be expected that 2,000 r would be lethal to almost all radiosensitive cells such as lymphocytes, 200 r considerably lethal and 50 and 25 r only lightly damaging.

The results are shown in Table 2. In each case treatments estimated to be lethal to intact cells has resulted in loss of potency.

The other line of work has been a continued attempt to find positive effects from heterologous material. In our previous studies, unlike Lorenz *et al.*, we had no success in mice with heterospecific spleen and bone marrow from rabbits or guinea pigs. This was in spite of the fact that the guinea pig material was known to be effective for our own guinea pigs.

In the present study antigenic dif-

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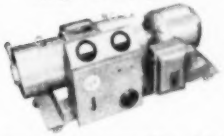

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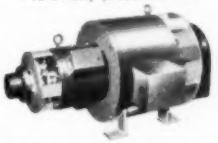

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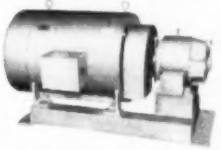

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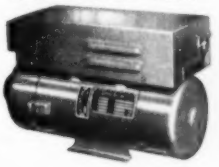

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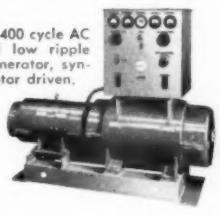

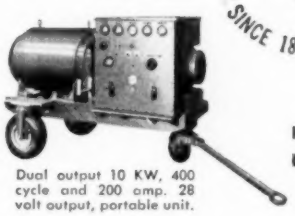

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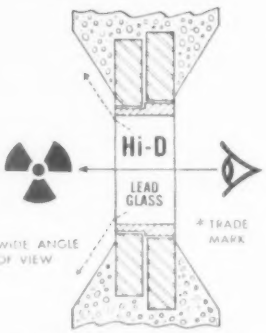

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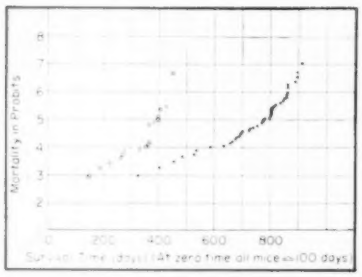
ferences within the mouse species were investigated. The CBA mouse was retained as the recipient. Infant donors were chosen from two groups: homologous CBA mice of the same colony, and heterologous strain A mice, known to be antigenically different from CBA mice, who readily produce haemagglutinins after injection of A material (8). The two groups were each further subdivided into: those for whom the therapeutic dose was the first administration of cells, that is "unimmunized," and second, those who had had two previous doses of similar material to immunize them if they were capable of reacting by formation of antibodies.

The results are given in Table 3. Within the CBA strain, all members of which should be reasonably genetically and antigenically identical from inbreeding, previous exposure to the cellular material makes no difference to the response. On the other hand, when heterologous strain-A material is given, on the first administration an increased recovery is demonstrated, but not when the therapeutic dose is given to animals in the immune state. The results suggest that the effective agent is antigenic, that is cellular, or if chemical, of a protein or haptenic nature.

The apparent disagreement between the results of Lorenz *et al.* and ourselves with heterologous material needs comment. This could readily be a matter of scoring. The conventional method is to score survival at 30 days. Heterologous material can survive for a while as a homograft and then is destroyed by developing antibodies. Thus, in Table 3, heretologous strain-A material appears active on its first and only exhibition—over 50% survival at 30 days. However, all of these mice died soon after the 30th day. They are therefore only academic survivors.

With homologous material the survival of the irradiated mice is normally for some hundreds of days. There is undoubtedly a shortened expectation of life of these recovered mice, but it is not possible to assess quantitatively the amount.

This problem was not specifically investigated or controlled, but the survivors are being retained until their death. It is perhaps permissible to compare results to date with a normal stock of the same strain who were kept in the same laboratory but not under identical conditions by R. H. Mole. The illustration on this page demon-



SURVIVAL of heterologous vs homologous material

strated the survival of the two groups. Dr. Mole and his collaborators will be publishing their results elsewhere and will discuss the possible reasons for the curvature of survival graphs plotted in this way.

We are aware of the continued work of Cole *et al.* (*9*), who demonstrated that the most active fraction of spleen homogenate differentially centrifuged was that which was mainly cell nuclei. But this fraction did contain some intact cells, and naked cell nuclei are very difficult to distinguish from normal lymphocytes. We would consider these results more indicative of absence of effect from cell fragments—microsomes and mitochondria—than absence of effect from intact cells. In a subsequent communication Cole and Ellis (*10*) report that desoxyribonuclease and trypsin destroyed the activity of the homogenate whereas ribonuclease did not. This would be more convincing evidence of the chemical nature—desoxyribonucleoprotein—of the active agent if the nucleases were pure and free of protease. The conditional clause is important. As matters stand we feel that the chemical hypothesis has not been proved by the complete exclusion of the cellular hypothesis.

—D. W. H. Barnes and J. F. Loutit
M.R.C. Radiobiological Research Unit
Atomic Energy Research Establishment
Harwell, England

BIBLIOGRAPHY

1. L. O. Jacobson, E. L. Simmons, E. K. Marks, L. O. Gaston, M. J. Robson, J. H. Eldridge, *Science* **113**, 510 (1951).
2. L. O. Jacobson, *Cancer Research* **12**, 315 (1952).
3. D. W. H. Barnes, J. F. Loutit, *Proc. Roy. Soc. Med.* **46**, 251 (1953).
4. L. J. Cole, M. C. Fishler, M. E. Ellis, V. P. Bond, *Proc. Soc. Exp. Biol. Med.* **80**, 112 (1952).
5. E. Lorenz, D. Uphoff, J. R. Reed, E. Shelton, *J. Nat. Cancer Inst.* **12**, 197 (1951).
6. M. E. Hillinger, J. H. Ferguson, P. A. Bienenschneider, *J. Lab. Clin. Med.* **42**, 581 (1953).
7. E. Lorenz, C. Congdon, D. Uphoff, *Radiology* **58**, 863 (1952).
8. P. A. Gorer, *Brit. J. Exp. Pathol.* **17**, 42 (1936).
9. L. J. Cole, M. C. Fishler, V. P. Bond, *Fed. Proc.* **12**, 27 (1953).
10. L. J. Cole, M. E. Ellis, paper presented to Radiation Research Society (June, 1953).

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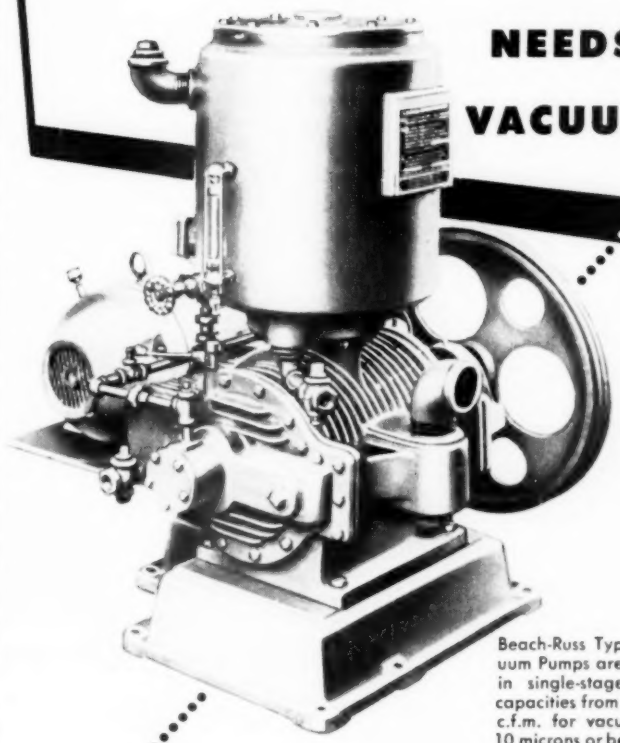

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Groups actively working on the program include Oak Ridge National Laboratory (ORNL), Argonne National Laboratory (ANL), Westinghouse Atomic Power Division (WAPD) of Westinghouse Electric Corp., Duquesne Light Co., and North American Aviation Corp. (NAA). The last three are private firms working under AEC contract. It is particularly noteworthy that Duquesne and NAA are contributing sizable amounts of their own money to the program

AEC has stated that the program was formulated with the hope that the new technology developed by the program "will encourage industry to take over an increasing share of the financing of further research and development and to consider with increasing favor the actual construction of pilot or full-scale power plants. The progress of this program and the extent and growth of industrial effort will assist in determining the course of future work." The program is "based

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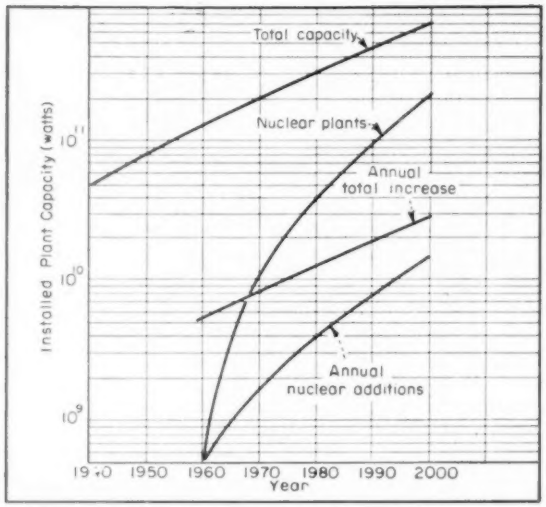
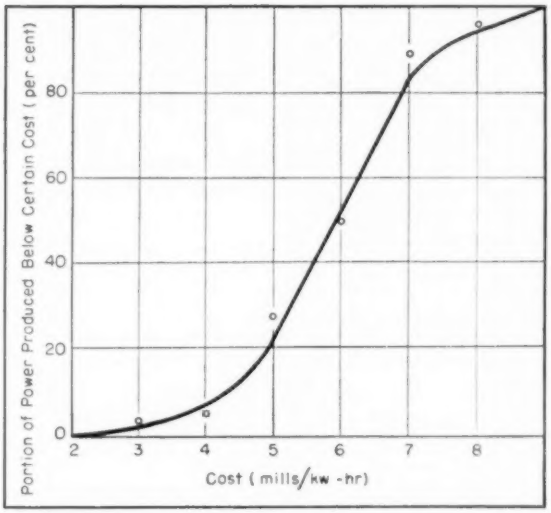
ORNL	5	1‡	3	1956	1	Fuel and moderator in aqueous uranyl sulfate solution. Chemical processing plant and turbogenerator included. Excess heat exhausted to atmosphere.	Simple, reliable plant to demonstrate practicality, study corrosion, chemical processing, operation. Potential advantages: simplified design, no fuel element fabrication, low-cost chemical processing.
Homogeneous Thorium (HTR)							
ORNL	65	16	44	1959	1	Two integral processing plants: one for fission-product removal, other for U^{233} separation.	Demonstrate U^{233} production from Th blanket. Startup with U^{235}, eventually use U^{233} from blanket.
Fast Breeder (EBR-2)							
ANL	62.5	15	40	1958	2	NaK coolant. Operating conditions, components similar to full-scale power reactors. Loaded first with U^{235}, later with Pu.	Test engineering features; component design; fuel handling; power cycle, core, blanket variations.
Boiling Water (EBWR)							
ANL	20	5	17	1956	3	Enriched U, cooled and moderated by natural or heavy water. Enrichment necessary for any H_2O or small D_2O reactor.	Define maintenance problems caused by radioactive deposits on power-plant components.
Sodium-Graphite (SRE)							
NAA	20	None	10§	1956	4	Tank-type core. Slightly enriched U (regeneration ratio ~0.9), or Th and U^{233} (ratio slightly better than 1). Heat exhausted to atmosphere.	Determine upper limits of fuel and coolant temperatures, burnup, etc., test fuel element performance, structural integrity, corrosion.
Pressurized Water (PWR)							
WAPD	264	≥60	85¶	1957	5	H_2O coolant, moderator. Fuel at >600° F, coolant at 500–600° F and 2,000 psi, steam at 600 psi, max. heat flux = 350,000 Btu/ft²/hr, avg power density = 45 kw/liter, avg specific heat power = 1,000 kw/kg of fissionable material, core = 6 ft dia × 7 ft high, pressure vessel = 9 ft dia × 28 ft high, fuel = 15–20 tons of U of 1.5–2% U^{235}.	Only full-scale plant. Will yield operating experience and cost data. Demonstrate large pressure-shell design, long irradiation cycle for fuel elements, controls for a very-closely-spaced fuel element design. Fuel elements inserted through pressure shell.

* Includes development. † These are long-term ratings for production of economic power (based on consensus expressed by 17 scientists in JCAE subcommittee hearings) but are only significant in that they give a relative feel for the state of the art. Actual experience may cause revision. ‡ Capability. HRE-2 on HRE-1 site; same turbogenerator—thus only few-hundred kw actually will be generated. § Includes $2.5-million from NAA. ¶ See NU, April '54, p. 78.



PROJECTED GROWTH of U. S. electric power industry will be at rate of about 4.4%/yr (nation's long-term economic growth has been at rate of about 3%). If AEC and industry can meet production-cost goals, 1960 will mark accomplishment of competitive (8-mill) nuclear power; between 1960 and 1970, nuclear plants will account for 10–20% of all new generating facilities; gradual improvements will cut costs until, by year 2000, about 22% of total capacity and 50% of new plants will be nuclear-fueled (at 6-mill cost). Between 1960 and 1985 nuclear units will use $11-billion worth of equipment (reactor, cooling, and power conversion)



COMPETITION facing nuclear plants is shown by considering portion of plants producing power below certain cost. If nuclear plants can produce power for 7 mill/kw-hr they can compete for 16% of the market. If costs are cut to 5.9 mills, 50% of market is opened; 4.9-mill nuclear power could attract 80% of market. Curve is based on 6,500 Mw in 26 plants (conventional) recently built in U. S. All were larger than 100 Mw. AEC believes that production costs of conventional plants will stay constant—any gains in technical efficiency will be offset by rising costs of conventional fuels

(Data presented by R. P. Petersen, AEC, before Atomic Industrial Forum.)

. . . An Expanding Nuclear Power Industry

on the assumption that the law will be changed to make industrial participation in reactor development more attractive."

To lower nuclear power costs, the program aims to achieve higher fuel-burnup before chemical reprocessing becomes necessary, lower fuel-processing and fuel-element fabrication costs, and increased thermal efficiency. EBR-1 has thermal efficiency of 17%, and HRE-1 14%; the plants in the five-year program are expected to achieve 25% efficiencies. Full-scale liquid-metal reactors should reach 35%, which is equivalent to the efficiencies of large, new conventional power plants.

Higher burnup and improved resistance to radiation damage may be attained by alloying. Simple methods of fabricating fuel elements from partially-reprocessed fuel also may be useful in reducing costs of certain types of reactors.

Homogeneous

Homogeneous reactors eliminate need for fuel-element fabrication and handling and simplify reactor design. They also permit low-cost continuous chemical processing. Their present technology makes them excellent long-term prospects for low-cost power (short-term approaches are considered less likely to produce competitive power).

HRE-1, now being dismantled at Oak Ridge National Laboratory, demonstrated the stable power output of a 1,000-kw homogeneous reactor. It used circulating uranyl-sulfate fuel at nearly 500° F under 1,000-psi pressure. It had a power density of 30 kw/liter and showed that homogeneous reactors can be safely operated and maintained even with their highly-radioactive liquid fuels and with radiation-induced evolution of hydrogen and oxygen. HRE-2 will be assembled in the building vacated by HRE-1.

Breeders

EBR-1 is still operating in Idaho; it will yield further information on fast-breeder physics, fabrication methods, chemical processing, and radiation damage.

Fast-breeder research is continuing. Argonne National Laboratory has a neutron source reactor that provides neutrons for reactor physics measurements on subcritical core configurations. Data from this are being used to design a critical assembly to be built at the Idaho testing station. The criticality unit will define critical mass, breeding ratio, and power distribution. A mechanical mockup at ANL will test loading and unloading devices, controls, heat exchangers, boilers, and superheaters.

Pressurized Water

The pressurized water reactor will provide the first full-scale demonstration of the generation of electricity from nuclear energy in the United States.

The subcommittee suggested that the committee meet with AEC before any further action was taken on the PWR (see *Washington Report*). The meeting was recommended "to insure that both the committee and the Commission are in agreement on its (PWR's) continuation, appreciate its limitations, and have a clear conception of what it can be expected to accomplish."

Although PWR is of conservative

Overhaul of Atomic Act Proposed by JCAE

Complete overhaul of the 1946 Atomic Energy Act is proposed by the Joint Congressional Committee on Atomic Energy to:

- **Permit creation** of a domestic nuclear power industry financed by either public or private groups.
- **Permit limited exchange** of atomic energy military information with allies of the U. S.
- **Permit the U. S.** to share information and fissionable material with friendly nations for peaceful exploitation of nuclear technology.

Besides greatly broadening the scope of the Act, the proposed changes also relate to the organization of the Atomic Energy Commission, classification of information, and review of certain Commission actions.

Public hearings were scheduled to start May 3, with May 10–17 reserved for public hearing of volunteer witnesses. Following the public hearings, the Joint Committee planned closed-door sessions to write the final version of the bill.

In their present form, the amendments go beyond the changes requested by President Eisenhower (NU, March '54, p. 74). He did not ask for legislation to permit cooperation with foreign nations on peacetime uses, which the amendments would provide.

In general, the amendments would provide incentives requested by private industry during hearings last summer (NU, Sept. '53, p. 10) to encourage industrial development of nuclear power.

AEC would retain title to all fissionable or other fuel material used for production of nuclear power in commercial quantities. This material would be available to licensees at reasonable rates fixed by AEC.

Conventional patent rights would be permitted in the peaceful applications of atomic energy. AEC also would establish standard specifications, including a royalty fee, upon which it may grant a permit to use any patent it now holds.

The Commission would license construction and operation of nuclear power reactors by nonfederal enterprises under these conditions:

- Applicants for license would have to meet technical and financial qualifications prescribed by AEC in its rules or regulations.
- Full and complete plans of the proposed facility and all

---

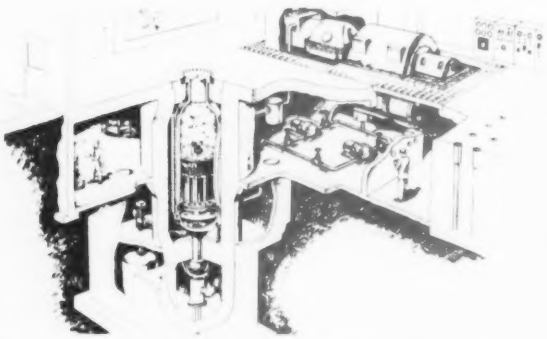
design and has a poor long-term prospect for producing low-cost power. AEC expects it to yield valuable operating experience and cost data. The subcommittee concluded that the PWR also might contribute substantially to the President's proposal for international cooperation. With minor redesign, the reactor could operate on natural uranium if heavy water were used as the moderator. It soon could provide many parts of the world with economic nuclear power. Thus, the subcommittee concluded that "as a demonstration of the serious intent of the United States to develop peacetime uses of atomic energy for both ourselves and our allies and as a tool to help gain operating experience on a full-scale plant, the continuation of construction of one large-scale plant such as the pressurized water reactor is important."

Site. PWR will be built in Beaver County, 25 miles northwest of Pittsburgh, on a 400-acre Ohio River site.

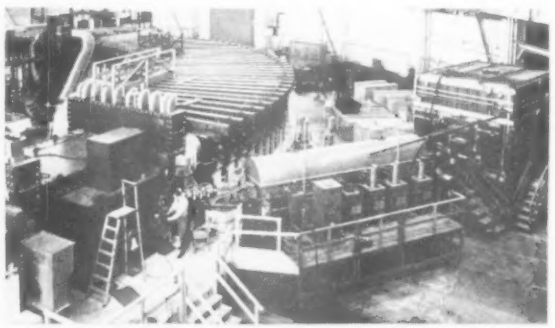
General Research

AEC also is continuing its general reactor research and development program. Reactor physics, radiation damage, shielding, control, heat transfer, and fuel studies are being made. An experimental fuel-element fabrication facility to study recycling will be built at Argonne National Laboratory. The general studies also include recovery of uranium, plutonium, and thorium from used fuel, radioactive-waste treatment and disposal, and constructive use of waste-fission-product radioactivity.

Witnesses before the subcommittee stressed the importance of project participants having enthusiasm for their particular reactor types. The subcommittee concluded that "proponents of each particular type of reactor proposed for pilot testing appear to have



EXPERIMENTAL BOILING WATER REACTOR will convert water into steam directly without use of intermediate heat exchange system. Cutaway of pressure vessel of ANL's 5,000-kw (electric) experimental unit shows how heat generated in fuel assemblies is transmitted to water to make steam. Turbine, electric generator, condenser, pumps, control room, and fuel element storage also are shown



MOST POWERFUL ACCELERATOR, the Bevatron at the University of California, has accelerated protons to 5 Bev. Particles from ion source were boosted to 0.5 Mev by the Cockcroft-Walton generator (right), to 10 Mev by the linear accelerator (center), and to 5 Bev by the Bevatron (left). The 10,000-ton, 120-ft-dia magnet is designed for 6.25 Bev. AEC financed the $9-million machine

pertinent information as to use, fuel requirements, location and all specifications would be part of the application.

• Under unusual circumstances, AEC may recapture the fuel material of a licensee in advance of a hearing under review procedures.

The amendments also provide for a special three-man review board, within AEC but independent of its other activities, to handle appeals from licensing rulings. Board members would be appointed by the President, with the advice and consent of the Senate, to serve for 7-year terms.

Further appeal procedure also is provided. Once the review board has acted on a licensing matter, the case may be taken to the federal courts at the instance of the interested party or the Commission. However, the proposed amendments would prohibit any court action that AEC and the National Security Council find will necessarily disclose restricted material.

Provision also is made in the proposed amendments for sharing of information and fissionable material with foreign nations, but only under rigid conditions. Under no circumstances is information on the design or manufacture of atomic weapons to be shared with foreign nations.

In reshaping AEC procedures on personnel clearances, the Committee proposes a classification of positions based on importance of restricted material to which an employee will have access. Scope and extent of security investigations would be based on the relative importance of the position.

One proposed new section to the Act is almost certain to draw opposition from AEC. This would give the "restricted" classification on documents a three-year life. To retain this classification on information, AEC would have to make a specific finding that the secrecy tag was still required in the interest of defense and security.

The Committee's amendments would also tighten the present law regarding the transmission of restricted information to unauthorized persons. For such disclosure, whether with criminal intent or not, a government employee or an employee of an AEC contractor would be liable to a fine of $2,500. The person receiving the restricted data would be subject to the same fine if he communicated it to other unauthorized persons.

enthusiasm in the prospects for achievement of economic power by the approaches which they advocate. There is apparently little optimism about the . . . pressurized-water reactor."

House Cuts AEC Budget, Reactor Program Okayed

The House of Representatives voted the full amount of funds requested by the Atomic Energy Commission for its fiscal-1955 power-reactor program (see p. 72) but trimmed other parts of AEC's budget.

The House also authorized initiation of construction on one or more power reactors, should development progress that far. Unlike other AEC obligations, the authorization permits reactor construction to be started without requiring that funds be appropriated for the entire cost of the project.

Unearthed by the House economizers was the $85-million reactor development budget item from which most of the power-reactor funds will come. Also unchanged was the $35-million requested for continuing construction on the pressurized water reactor now on the drawing boards at Westinghouse.

Over-all, the House voted $1.2-billion for all AEC activities during the year beginning July 1. This is $131.1-million above the total AEC budget for the present fiscal year, but still $152-

Washington Report

Controversial PWR project—only utility-scale U. S. nuclear power plant now in the advanced design stage—came near being torpedoed by the Joint Congressional Committee. Strong assurances from AEC saved it. The crucial action came just two days before AEC accepted the Duquesne Light Co. partnership offer on the project. Here is the sequence of events:

▶Testimony and correspondence from the nation's top reactor experts received during February and early March by a subcommittee of the Congressional group cast considerable doubt as to whether PWR should be continued as a full-scale plant.

▶The subcommittee asked for a temporary halt on PWR until it could discuss fully with AEC the feasibility, limitations and purpose of the reactor. There was a strong possibility that the subcommittee would ask that the project be halted or at least drastically scaled down.

▶At a closed-door meeting March 12th three Commissioners and AEC reactor chief Lawrence R. Hafstad promised to make every reasonable effort to incorporate new ideas into PWR to make it more economic. They also made other still-undisclosed commitments regarding the PWR project.

▶This was what the subcommittee wanted. It cleared the project, and AEC announced the Duquesne agreement two days later.

•

Exclusion area requirements for power reactors are being drastically trimmed. If the normal exclusion area formula had been used, the PWR site would have required a plot of land of around 30 square miles. Actual site is a small fraction of that. One of the major aims of the AEC program is to develop reactor types suitable for conventional power plant locations.

•

"Five-Year Reactor Development Program" is really a misnomer. Development schedules will be pretty much set by the men in charge of the five projects. Each will be allowed to speed up or slow down his experiment as conditions permit. The Congressional Committee has agreed to this.

•

President Eisenhower will bring in his own man when AEC Commissioner Eugene M. Zuckert's term expires June 30. Until then, there is a majority of Truman appointees on the five-man Commission.

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Ripple: less than 10 millivolts
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Dual Teflon-insulated H.V. output connectors
4 1/2" direct reading panel meter.

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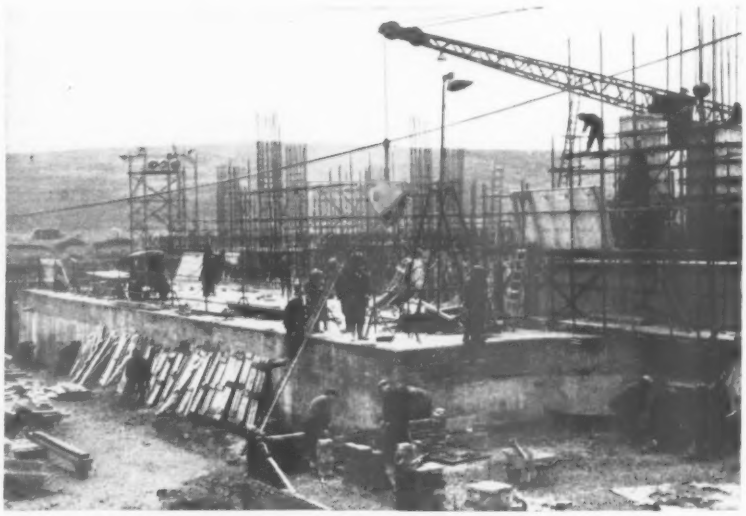

REACTOR FOUNDATION for Britain's first nuclear power station is under construction adjacent to Windscale plutonium production piles at Calder Hall, Cumberland (NU, Feb. '54, p. 74; Dec. '53, p. 70). Construction will be completed in mid-'55. Second British nuclear power station (at Dounreay, Caithness, Scotland) will cost about $42-million (NU, March '54, p. 61; Dec. '53, p. 70)

million less than the amount requested by President Eisenhower.

Most of the cut appears to be a bookkeeping matter designed to reduce contingency funds now held by the agency. In all, $122-million of the $152-million reduction is charged to this transfer of funds. On the construction side, sizable cuts ($12-million) were made in requests for new ore-processing plants; miscellaneous budget items were sliced by $5-million. On the operations side, $3.1-million in cuts were made in physical-research projects and administration expenses were pared by $2.7-million.

A rundown of the appropriations picture for each of the civilian power-reactor projects shows:

1. **Pressurized-water reactor**—$35-million for construction and $6.5-million for development was approved by the House for the next fiscal year. For the present year, $5-million has been allocated to the project.

2. **Fast-breeder project**—$3.7-million approved for next fiscal year, $10-million previously allocated for this program.

3. **Sodium-graphite reactor experiment**—$2.5-million approved for next fiscal year, $4-million previously allocated.

4. **Boiling-water reactor experiment**—$2.3-million for next fiscal year, $3-million previously allocated.

5. **Homogeneous reactor experiment**—$4-million for next fiscal year, $15-million previously allocated.

Also in the development budget is $14.2-million for the aircraft propulsion reactor program and $25.6-million for the naval propulsion reactor program.

The following table shows amounts available for total AEC operating and plant and equipment budgets. It includes new money as well as that available from prior appropriations.

Item	*Budget ($ \times 10^6$)*	
	Operating	*P & E*
Source and fiss.	740.0	247.5
Weapons	320.9	34.8
Reactor dev.	87.0	51.1
Phys. res.	38.9	23.6
Biol. and med.	26.6	0.5
Community	−1.0	2.3
Prog. admin.	33.0	
Secur. invest.	10.9	
Equip. not incl. in constr. proj.		29.8
Totals	1,256.3	389.6
Reductions still undistributed		5.0

House authorization, if upheld by the Senate, will permit AEC to let contracts during the next fiscal year on the Army package reactor estimated to cost not more than $3-million. This reactor is designed for use at military installations (NU, March '54, p. 75). It will develop a normal full load of 1,250 electrical kw and a maximum peak load of 1,500 kw.

For operation of service reactors and

facilities such as the materials testing reactor in Idaho, the chemical processing plant at the same site, the Oak Ridge School of Reactor Technology, and other related activities, the House approved $9.2-million—up $1-million above the current year.

For advanced engineering and development in the general field of reactor technology, $12.5-million was approved—the same amount as is available for the current year.

AEC in Process of Being Reorganized

Slight increase in staff, shift of production responsibilities from the New York to the Oak Ridge operations office, transfer of a Livermore Research Laboratory project from California Research and Development Co. to University of California's Radiation Laboratory, and plans for naming four assistant general managers are among changes taking place in AEC.

During the fiscal year beginning July 1, AEC is asking funds to increase its staff personnel from 6,774 to 6,898. Both these figures are several hundred below the number the agency is actually authorized to hire.

K. D. Nichols, general manager of AEC, recently announced transfer of feed materials production responsibilities from the New York office to the Oak Ridge office effective July 1. The New York office will be maintained to supervise the health and safety laboratory in New York City, Brookhaven National Laboratory at Upton, N. Y., and about 275 research and development contracts, chiefly with universities and laboratories.

Officials were not immediately certain how many New York employees would be affected by the transfer, but said it would not be enough to offset reductions now planned for AEC activities at Oak Ridge.

The California Research and Development Co. contract for work at Livermore (understood to be connected with thermonuclear weapons research) will not be extended upon its expiration on June 30. The project will be continued by the University of California Radiation Laboratory at a reduced level of effort. UCRL has conducted a separate research program at Livermore since 1952.

Nichols is understood also to be considering naming four assistant general managers. R. W. Cook has been appointed assistant general manager

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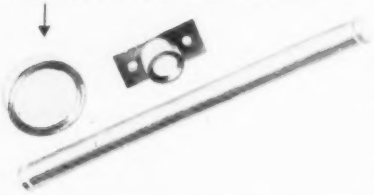

Beta Gauge.....Ra, RaD, Sr^{90}, Tl^{204}
Liquid Level Gauge.....Cs^{137}, Ru^{106}, Co^{60}
Standards.....Alpha, Beta, Gamma

NEUTRON SOURCES

Min. Emission
Ra .....1.3 x 10^4 n/mc/sec
RaD ..... .26 x 10^4 n/mc/sec
Po ..... .26 x 10^4 n/mc/sec

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for manufacturing. He will continue to serve as acting director of production. Alfonso Tammaro will be assistant general manager for research, reactor development, biology and medicine, and industrial development. (Previously Tammaro reported to L. R. Hafstad, chief of reactor development; now Hafstad will report to him). Not yet selected are an assistant general manager for administration (to include personnel relations, classification, and security) and an assistant general manager for military projects.

J. J. Flaherty, manager of the San Francisco field office, will succeed Tammaro as chief of the Chicago operations office. Edward J. Bloch, formerly director of the division of construction and supply, succeeds R. W. Cook as director of the production division. John A. Derry, former assistant director of the production division, succeeds Bloch. Frank K. Pittman, former assistant director of operations in the production division, is now a deputy director of that division. He succeeds Neil J. Carothers, who has accepted a position as assistant to the president of Albert M. Higley Co., Cleveland. William K. Maher, former assistant director for construction and engineering in that division, also has been named a deputy director of the production division. George F. Quinn, former chief of the pile products branch of the production division, succeeds Pittman. W. Kenneth Davis, former manager of the research division of California Research and Development Co., has been appointed assistant director (technical) of the division of reactor development. R. E. Hollingsworth, former chief of administration in the production division, has been appointed assistant director of the division.

Sterilization Program Transferred to Army

Funds allotted to food sterilization research will be just about doubled when this phase of the atomic energy program is transferred from the Atomic Energy Commission to the Department of Army on June 30. AEC's division of reactor development has spent about $\$1\frac{1}{2}$-million in about $3\frac{1}{2}$ years on this phase of fission-product utilization. Army's Quartermaster Corps is planning a $6-million research program for the next five years.

Immediate effect of the change is to remove duplication of effort. Quartermaster has been experimenting with radiation sterilization on a small scale for about five years, but major results to date have come from the AEC program. Now, AEC will be able to concentrate on other phases of fission-product utilization. Current plans are to expand research on promotion of chemical reactions (use of radiation as a catalyst) and on basic radiation technology.

Quartermaster will coordinate radiation sterilization studies through its Food and Container Institute in Chicago. Some research will be done at the Institute, but most projects will be carried on by universities and industry under contract. AEC has 15 contractors in the present program; to date, 8 or more institutions have discussed contracts with Quartermaster.

The Quartermaster program, while approved by the Department of Army, has not yet been allotted funds by Congress for next year. Appropriations will be on an annual basis.

The new program will be based on recommendations of a subcommittee of the Committee on Foods of the National Academy of Sciences—National Research Council Advisory Board on Quartermaster Research and Development.

AEC Authorizes Three New Reactor Studies

Three new power reactor study projects have been authorized by the Atomic Energy Commission. Industrial firms and groups now have 11 such studies in progress—all looking toward the development of economic nuclear power.

Recent additions include studies by Babcock and Wilcox Co., Bendix Aviation Corp., and American Machine and Foundry Co.

AEC Forms Army Reactor Branch; Lampert Head

An Army reactors branch headed by Col. James B. Lampert was established by AEC in mid-March with the immediate aim of developing and constructing a package power reactor for military use. Lt. Col. W. C. Gribble is deputy chief of the branch.

The action raises Lampert from a liaison officer between the Army Corps of Engineers and AEC to full operational status in the civilian agency. Lampert's position is similar to Rear Admiral H. G. Rickover's role as head of the naval reactors branch and Brig.

Gen. D. J. Keirn's role as chief of the aircraft reactors branch.

The Army reactor study was initiated in November, 1952, and the package reactor work has been its main responsibility. In addition to his AEC position, Lampert also is special assistant for nuclear power to the Army's Chief of Engineers.

Other responsibilities of the new branch are:

1. Planning and giving staff direction to the development and construction of reactors for Army purposes.
2. Study of future reactor needs of the Army.
3. Direction of related research activities.

Compton Heads Northeast Nuclear Industry Study

A 12-member committee to study the peacetime uses of atomic energy in the Northeast has been named by the New England Governors Conference. K. T. Compton is chairman of the group.

IRE Nuclear Group Plans Conference Oct. 6, 7

The Institute of Radio Engineers' Professional Group on Nuclear Science will hold its first annual national conference in Chicago, Illinois, October 6 and 7, 1954, at the Sherman Hotel.

The theme of the conference will be nuclear reactor technology, particle accelerators, and nucleonic instrumentation. A review of European reactor technology will be presented.

The first day's session will coincide with the last day of the meeting of the National Electronics Conference.

Papers are invited and should be twenty minutes in length. Titles and abstracts should be submitted before June 1st to T. Brill, Argonne National Laboratory, Box 299, Lemont, Illinois.

MEETINGS

May 24: Atomic Industrial Forum's Meeting on AEC's Five-Year Reactor Program; Sheraton Park Hotel, Washington, D. C. L. R. Hafstad, A. M. Weinberg, and W. H. Zinn are among the speakers scheduled for this second Forum-sponsored meeting.

June 20-25: American Institute of Chemical Engineers' Nuclear Engineering Congress; Ann Arbor, Mich. (NU, Aug. '53, p. 64). Arrangements: write R. R. White, Univ. of Mich., Ann Arbor.

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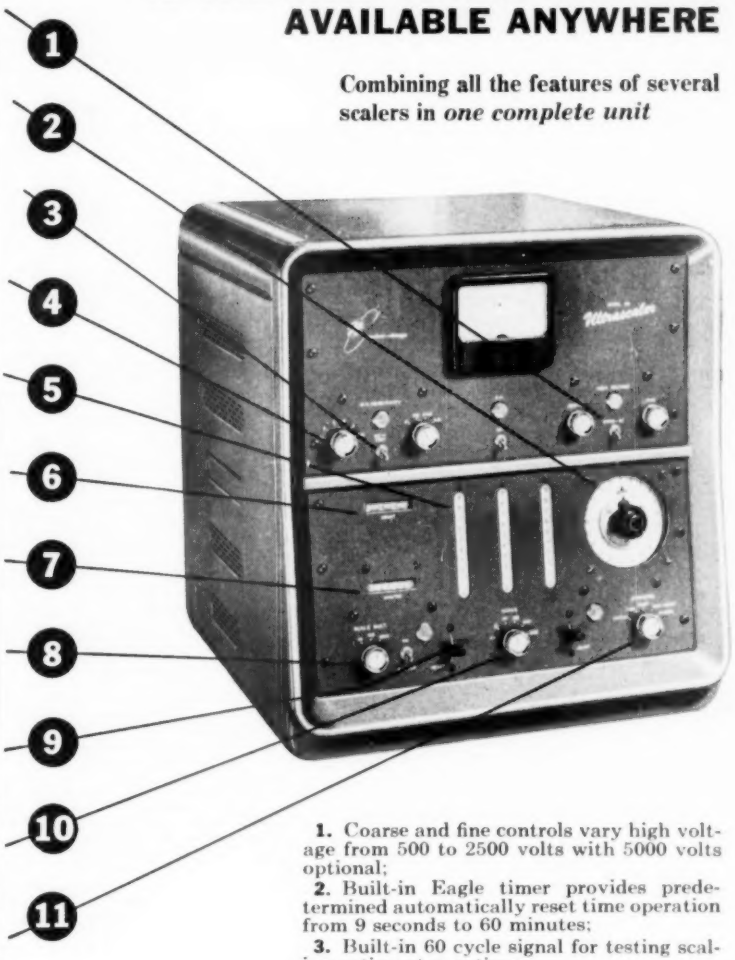

1. Coarse and fine controls vary high voltage from 500 to 2500 volts with 5000 volts optional;
2. Built-in Eagle timer provides predetermined automatically reset time operation from 9 seconds to 60 minutes;
3. Built-in 60 cycle signal for testing scaling action at any time;
4. Sensitivity controls permit counting with *any* Geiger, scintillation or proportional detector;
5. Direct reading decade scaling units;
6. Built-in four digit electrically reset register;
7. Built-in timer indicates counting time up to 9999.99 minutes;
8. Scale multiplier switch permits wide range of count settings;
9. Electrical reset switch for plug-in units, timer, register and Eagle timer;
10. Six position scale selector switch for scaling factors up to 1000;
11. Operation switch for selection of manual, predetermined time, predetermined count, "time-count," or remote operation.

Get all the facts about the New Model 192 ULTRASCALER: write today to:

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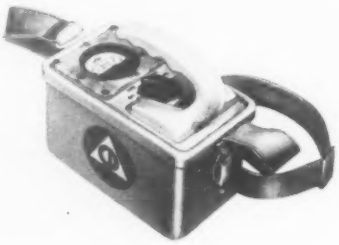
PRODUCTS AND MATERIALS

Counting-Rate Meter

The type 229 counting-rate meter, for general medical and laboratory measurements, provides a logarithmic scale (300–50,000 cpm) for general readings and six linear scales (0–100 to 0–50,000 cpm) for more precise readings. Accuracy on linear scales is 2.5% of full scale and on logarithmic scale, ±2% of full-scale meter radial deflection. High and low input sensitivity settings are 0.25 and 15 volts, respectively. High-voltage supply output is adjustable from 350 to 2,000 volts. Time constant is selectable corresponding to statistical error of 10, 5, or 2%. Also illustrated is the type 155 stainless-steel, 0.404-in. o.d. brain probe; minimum plateau length at 100 cps is 50 volts with slope of 10%/100 volts; background is 40 cpm at 600–650 volt operating voltage. *Anton Electronic Laboratories, Inc., 1226–1238 Flushing Ave., Brooklyn 37, N. Y.* (P-1)

Cancer-Therapy Machines

Two types of Co^{60} cancer-therapy machines are being marketed jointly by General Electric and Atomic Energy of Canada Ltd. The AECL 7,000-lb model A is stationary floor-mounted unit for sources providing up to 100 r/min at 70 cm. The AECL 16,000-lb Theratron, rotational cobalt unit, delivers 30 r/min at 70 cm; the source, on one end of C-shaped support, rotates by motor-drive continuously around the supine patient. Model A may be moved through arc of 105 deg; protection for direct beam is 40 in. of concrete, 7 in. of lead, or 7 ft of earth, and 12 in. of concrete or $^3/_{10}$ in. of lead for scattered radiation. Protection for direct radiation must be provided throughout rotational belt by 21 in. of concrete and for scattered radiation by 13 in. of concrete. *General Electric Co., X-Ray Dept., 4855 Electric Ave., Milwaukee 1, Wis.* (P-2)



Radiation Survey Meter

The Rad-Tek ionization-type survey instrument, approved by the Federal Civil Defense Administration, measures intensities of 0.02–50 r/hr. It operates on flashlight and hearing-aid batteries said to be capable of giving over 100-hr operation. *El-Tronics, Inc., 437 N. Fifth St., Philadelphia 23, Pa.* (P-3)

High-Temperature Transistors

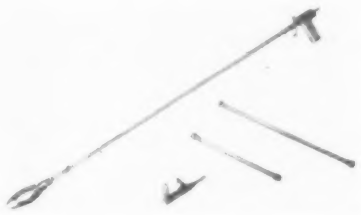
The Red Dot series of point-contact germanium diodes were developed for high ambient operating temperatures. Exposure to 95% relative humidity for 500 hr at 0–85° C does not appreciably change back resistance or cause hysteresis. Type G44 has a minimum of 100,000 ohms resistance at −30 volts and 100° C; other types may be ordered to specifications. These clip-in or solder-in diodes have $^3/_{32}$-in. diameter and $^3/_8$-in. length and No. 24 tinned-copper pigtailed leads. *International Rectifier Corp., 1521 E. Grand Ave., El Segundo, Calif.* (P-4)

Photomultiplier Shield

The model M-2 magnetic shield is especially intended for scintillation counting with 2-in. photomultiplier tubes having flat or dome-shaped end windows. It is constructed of two layers of hydrogen-annealed Mu metal. The $3^3/_4$-in.-long shield is attached to tube base with set screws. A similar shield, model M-1, is designed for $1^1/_2$-in. tubes. *National Radiac, Inc., 10 Crawford St., Newark, N. J.* (P-5)

Miniature Power Resistor

The type RSE miniature power resistor is available in 2, 5, and 10 watt sizes. Shock resistant and impervious to moisture, they are sealed in silicone coating and housed in completely welded black metal tubing. Temperature coefficient is 0.00002/° C. Ranges are 0.05–55,000 ohms; tolerances of 0.05–3% are available. *Dale Products, Inc., Columbus, Nebr.* (P-6)



Remote-Handling Tongs

The Radiarm, Sr, remote-handling aluminum tongs have three inter-

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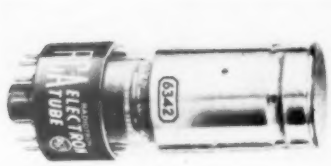
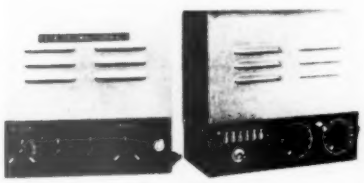
changeable shafts and two interchangeable jaws, scissor or monkey-wrench type, for small or large vessels and heavier objects, respectively. Jaw can be locked into fixed position. Shaft lengths from jaw to pistol handle are 22, 28, 46 in. *Atomic Center for Instruments and Equipment, Inc., 489 Fifth Ave., New York 17, N. Y.* (P-7)



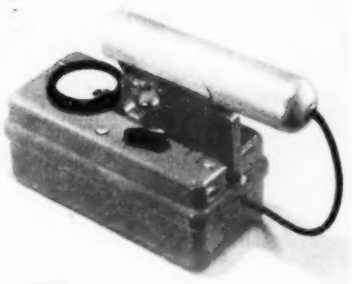
Photomultiplier Tube

The type 6342 10-stage head-on type photomultiplier tube is useful for fast coincidence scintillation counting. With input signal having rise time of 1 msec or less, rise time of response at the anode is ~5 mμsec between its 10 and 90% magnitude points at the maximum rated anode-supply voltage of 1,500 volts. Spectral response is S-4 with maximum response at 4,000 ± 500 Å. Focusing electrode with external connection permits optimizing magnitude, uniformity, or speed of response. Tube face is flat with $1\frac{1}{2}$-in. diameter; tube dimensions are $5\frac{13}{16}$-in. maximum length and $2\frac{1}{4}$-in. maximum diameter. *Radio Corporation of America, Tube Dept., Harrison, N. J.* (P-8)



Repeat-Cycle Electronic Timers

The models 2 and 3 repeat-cycle electronic timers provide on-cycle and off-cycle intervals, accurate in nominal changes of line voltage and temperature. Respective timer intervals are: on—0.2–150 and 0.01–6 sec; off—0.1–900 and 0.01–6 sec. Timers are available for a-c or d-c operation. *G. C. Wilson & Co., 1950 Eighth Ave., Huntington, W. Va.* (P-9)



Scintillation Survey Meter

The model 389F scintillation survey meter, for ground, laboratory, or aerial surveys, has probe clamped in the handle of watertight instrument case. Probe, 2 in. in diameter and $8\frac{1}{2}$ in. long, contains 6179-type phototube, $1 \times \frac{3}{4}$ in. NaI crystal, metal shield, and gain control. Probe is connected by 4-ft cable to ratemeter circuit box, which contains regulated vibrator-type power supply, d-c amplifier, and 3-range selector switch. One 4.5-volt and one 1.5-volt batteries are required. Calibration is cpm or mr/hr, on request. Alpha detector head is also available. *Victoreen Instrument Co., 5806 Hough Ave., Cleveland 3, Ohio.* (P-10)

Radiation Monitor

The type PW-4010 25-oz pocket-size radiation detector, 6.6 in. high, locates beta and gamma radiation. It is powered by 1.5-volt pen-light-type filament battery, two 30-volt miniature-type anode batteries, and 15-volt subminiature-type grid-bias battery. Halogen-quenched counter tube (type 18502) operates at 350 volts. Main switch has 6 positions: off, start, low sensitivity, high sensitivity, anode voltage, and filament voltage. Calibration switch has 4 positions: anode battery off and anode voltage 60, 55, and 47.5 volts. *North American Philips Co., Inc., Research and Control Instruments Div., 750 S. Fulton Ave., Mount Vernon, N. Y.* (P-11)

Liquid-Sample Counter

The model SC-12 liquid-sample NaI counting attachment, together with the SC-3 basic unit and LH-6 lead shield, is designed for low-level activity in samples up to 5 cm^3. The well of the $1\frac{3}{4}$-in.-diam. 2-in.-thick crystal is $2\frac{1}{32}$ in. in diameter and $1\frac{1}{2}$ in. deep. With the LH-6 shield, background is 200 cpm, sensitivity is 1,000 cpm, and efficiency is 50% for 1 mμc I^{131}. To accommodate different bottle heights, center section of sample cover is composed of threaded, lead-filled insert adjustable for sample size. *Nuclear Research and Development, Inc., 6425 Etzel Ave., St. Louis 14, Mo.* (P-12)

Universal Counter and Timer

The model 5510 direct-reading universal counter and timer measures and indicates time intervals from 3 μsec to 1,000,000 sec with maximum accuracy of ±1 μsec, frequencies from zero cycles to 1 Mc with maximum accuracy of ±1 cycle, period of frequencies from zero cps upwards with accuracy of ±1

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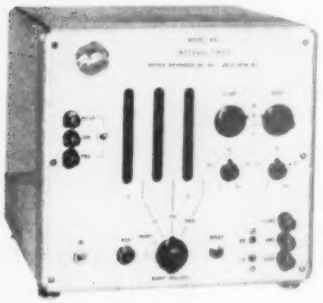
μsec, and operates as straightforward counter at rates up to 1,000,000 cps. It utilizes the model 705AF and 707AF decimal counting units, which provide binary coded output information for data reduction applications. Operation is automatic with display from 0.2–5 sec or manual with infinite display. *Beckman Instruments, Inc., Berkeley Div., 2200 Wright Ave., Richmond, Calif.* (P-13)

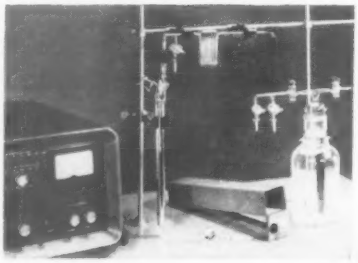


Interval Timer

The model 432 timer provides three ranges: 0.01–9.99 msec, 0.1–99.9 msec, and 1–999 msec. Instrument also serves as totalizing counter with capacity of 999 and as secondary frequency standard with outputs of 100 kc, 10 kc, 1 kc, 100 cps, 10 cps, and 1 cps. Control of start and stop for time-interval measurements may be by positive or negative pulse, contact closure or opening, or any combination of these. *Potter Instrument Co., Inc., 115 Cutter Mill Rd., Great Neck, N. Y.* (P-14)

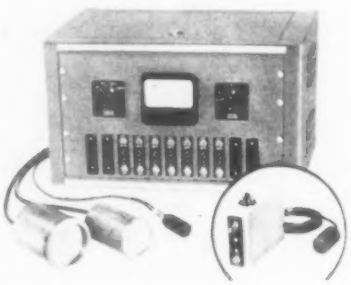
Cold-Cathode Counter

The model RC direct-readout, cold-cathode electronic counter operates at speeds up to 10,000 cpm with total capacity of 9,999,999. Counter consists of decimal unit preceding six-digit electromagnetic register. Input pulse is 30–70 volts, positive, with maximum rise time of 4 msec and minimum peak duration of 10 μsec. *Haledy Electronics Co., 57 William St., New York 5, N. Y.* (P-15)



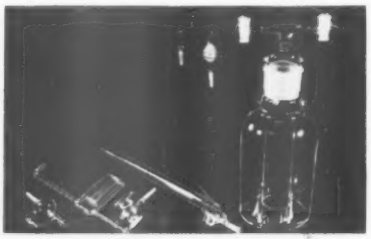
Assay Apparatus

This apparatus, for gaseous carbon-14 assay, employs a method that involves rapid combustion of radioactive organic samples by the Van Slyke-Folch technique, and assay of the resultant $C^{14}O_2$ with the Bernstein-Ballentine gas-filled proportional counter. The organic samples can be combusted and the gas measured manometrically and transferred to the proportional counter in 15 min or less. The radioactivity of the carbon dioxide can then be determined with high sensitivity and precision using the counter and the model 182X scaler. The count is proportional to the sample size over the entire range (0.1–15 mg) of the combustion. *Nuclear Instrument and Chemical Corp., 229 W. Erie St., Chicago 10, Ill.* (P-16)



Monitoring System

This remote-area monitoring system utilizes an inexpensive circuit for measurements from background to 100,000 r/hr, in several steps, from 1–10 remotely located ionization chambers. Low-voltage battery circuit permits operation of ionization chambers 5,000 ft from control panel without amplification. Control switch actuates solenoid-operated shutter in chamber assembly to block or permit β-rays to enter through 1-mil stainless steel chamber window. Second switch positions Sr^{90} calibration source in chamber for calibration accuracy of ±5%. Monitoring station plug-in unit consists of ionization chamber, cable, power supply, and controls. Chamber size and calibration source are optional. System is said to be substantially gamma independent between 75 kev and 1.3 Mev. *Jordan Electronic Sales, Inc., 119 E. Union St., Pasadena 1, Calif.* (P-17)

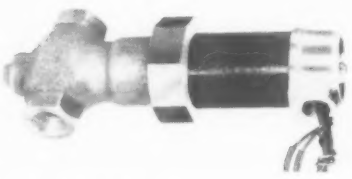


Carbon-14 Counting System

The Bernstein-Ballentine counting system for measuring carbon-14 activity in the gaseous phase accommodates 0.1–5.0 mg carbon samples. The Pyrex equipment consists of 100-ml gas-phase proportional counter (Bernstein-Ballentine tube), calibrator for determining counting sensitive volume, freezing coil for trapping water vapor, and methane reservoir. Counting tubes up to 1 meter by 20-cm diameter are available. Background is less than 150 cpm, unshielded. *The Atomic Center for Instruments and Equipment, Inc., 489 Fifth Ave., New York 17, N. Y.* (P-18)

Glass-Braided Lead Wire

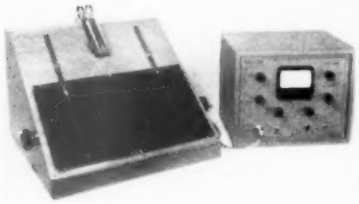
This glass-braided lead wire is for electronic and electrical components operating at temperatures from −55° to +200° C. Primary conductor insulation is Teflon; secondary insulation is Teflon-impregnated glass braid. Sizes are 28–10 awg, in any one of eight colors; special tracer colors are available. *Hitemp Wires, Inc., 26 Windsor Ave., Mineola, N. Y.* (P-19)



Solenoid Valves

These cast-iron and cast-steel solenoid valves are available in sizes ½ to 2 in. Pressures range to 1,000 lb/in.² at 200° F and 500 lb/in.² at 450° F.

Construction includes stainless-steel hooded pilot seat screw for positive closing action and Teflon disks inert to all media except hot flourine. Removable inserts are used throughout the range of sizes. Neoprene "O" rings seal joints. *Atkomatic Valve Co., Dept. 228, 545 Abbott St., Indianapolis 25, Ind.* (P-20)



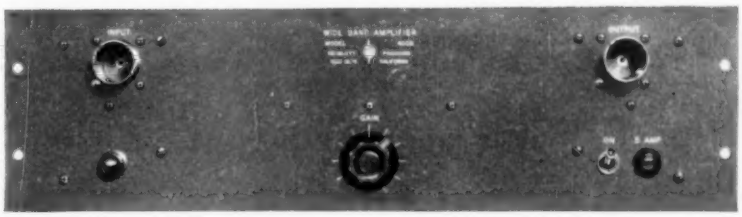
Densitometer

The model DSA-102 semiautomatic densitometer is designed for paper chromatography and electrophoresis. It permits quantitative evaluation of any size paper strip or sheet without cutting. Curves are plotted directly on the screw-driven table. Interchangeable slit and circular apertures for high-resolution scanning are provided. The signal from the red or blue sensitive phototube is read by means of a d-c amplifier. Adjustments are provided to balance out dark currents and background light, giving full-scale meter readings. *Matthew Laboratories, 345 Nepperhan Ave., Yonkers 2, N. Y.* (P-21)

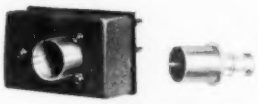
Dissolver

This "bottom-drive" model of the Ultrafast Dissolver has the motor mounted beneath the unit with the impeller shaft entering from the bottom of the tank. This is claimed to eliminate aeration and permits pressurizing of the tank. The machine is

Complete instrumentation for swift, sure, fast circuit measurements

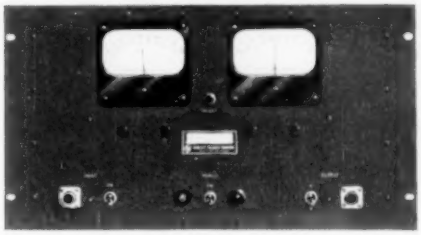


-*hp*- 460A Wide Band Amplifier

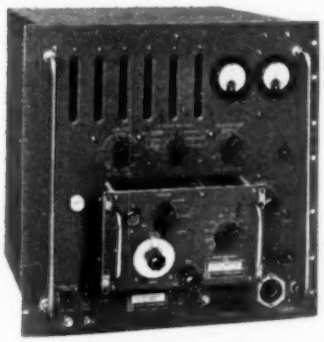


-*hp*- 46A Connectors

-*hp*- 520A High Speed Scaler



-*hp*- 410B Vacuum Tube Voltmeter



-*hp*- 524B Electronic Counter

-*hp*- 460 series Amplifiers give you up to 90 db gain in cascade, true amplification of millimicrosecond pulses, 0.0026 microsecond rise time, 125 volt open circuit output and 100 megacycles bandwidth for standard oscilloscopes. -*hp*- 520A High Speed Scaler is an aperiodic instrument for precision period pulse counting from 0 cps to 10 mc. Its double-pulse resolving time is 0.1 μsec, triple-pulse resolving time 0.2 μsec. -*hp*- also offers a complete line of electronic counters, oscillators, voltmeters, VHF, UHF and SHF signal generators and other equipment for nuclear radiation, television or similar work.

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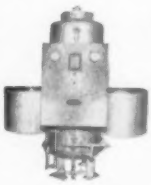
Penfield Mono-Column Demineralizer Model M-100. Purity of effluent: less than 2 ppm. Flow rate: 60-90 gph. Dimensions: 1½' x 2' x 7'. Features inspection window that allows easy inspection of crucial middle distribution system.



Penfield Mono-Column Demineralizer Model MA-1000. Purity of effluent: under 1 ppm. Flow rate: 1000-1200 gph. Dimensions: 2' x 5' x 5½'. Features automatic shut-off and signaling devices and fully automatic regeneration system.

Penfield Dual-Column Demineralizer Model UL-60. Purity of effluent: 5 to 10 ppm. Flow rate: 75-100 gph. Dimensions: 2' x 2' x 4½'. Features self-contained stainless steel control cabinet in which regenerant tanks are stored.

READY TO OPERATE ON ARRIVAL!

Available in a wide variety of mono-and multi-column models (flow rates from 10 to 10,000 gph), all Penfield Demineralizers come equipped with regenerant tanks and all necessary gauges, flow meter, conductivity meter, etc. On arrival at site, simply connect the completely "packaged" unit to service lines and start receiving super high purity Penfield demineralized water.

Any model Penfield Demineralizer may be secured with automatic shut-off and signaling devices and a fully automatic regeneration system. Special control systems for the automatic maintenance of the purity of storage tank water supplies also available.

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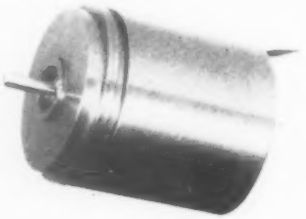
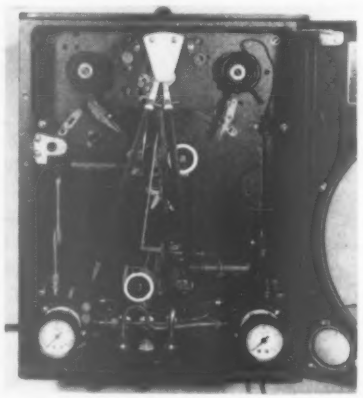
available in a wide range of tank capacities. Gear drives can be furnished. *Cowles Co., Inc., Cayuga, N. Y.* (P-22)



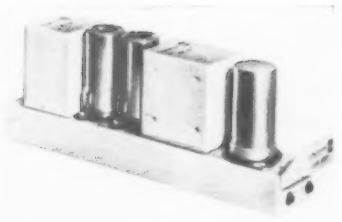
Miniature Resolver

The size 15 Telesyn resolver continuously performs trigonometric operations involving resolution of input voltages into sine and cosine components. Three models provide transformation ratios of 1:1, 4:1, and 8:1. Rotor is mounted in precision miniature ball bearings. Aluminum shell is recessed for flange mounting. Resolver is rated at 1-24 volts, 400 cycles input. It may also be used for such operations as synthesis of two voltages and rotation of coordinates. *Ford Instrument Co., 31-10 Thomson Ave., Long Island City 1, N. Y.* (P-23)



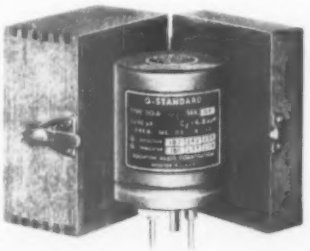
Temperature Control

This instrument indicates and controls two temperatures. It is available with wet and dry-bulb system for humidity as well as vapor gas or mercury-filled thermal systems. Dual indicator has two pointers; the measuring system components and setpoint indices are color-coded to their respective pointers. *Minneapolis-Honeywell Regulator Co., Industrial Div., Wayne and Windrim Aves., Philadelphia 44, Pa.* (P-24)



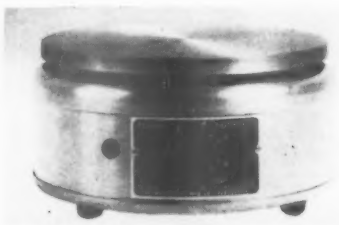
Miniature Amplifier

The model 5116 miniature amplifier is a plug-in two-stage low-noise preamplifier or booster amplifier. Gain is 40 db. Input impedance is 30, 150, 250, and 600 ohms; output impedance is 150 and 600 ohms. Output noise is equivalent to input of −120 dbm; output power is +18 dbm, less than 0.5% rms total distortion, 50 to 15,000 cps. Frequency is +0.5 db, 30 to 15,000 cps. *Langevin Mfg. Corp., 37 W. 65th St., New York 23, N. Y.* (P-25)



Q Standard

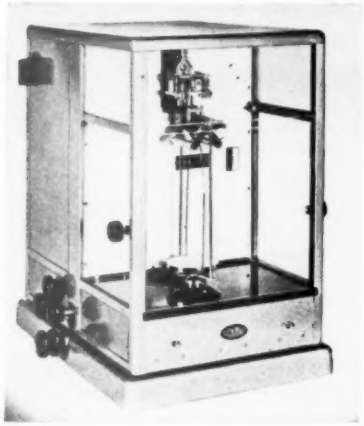
The type 513-A Q standard provides an accurately known Q and reactance and offers a convenient check for overall Q-meter performance. Nominal inductance is 250 μh and is specified to 1%. Distributed capacitance, with type 160-A or 260-A Q-meter, is 9.0 μμf, specified to 2%. *Boonton Radio Corp., Boonton, N. J.* (P-26)



Hot Plate

The model 2500 hot plate has continuously adjustable control from room temperature to 270° C. Surface plate temperature varies less than 3° over the heating range. The aluminum plate reaches maximum temperature

in 25 min. Power consumption at maximum temperature is 495 watt-hours. Sockets welded to the rear of case accommodate standard dovetail clamp and rod for support of apparatus above the plate. *Thermo Electric Mfg. Co., Dubuque, Iowa.* (P-27)



Analytical Balance

The model S-M single-pan analytical balance is said to minimize operator fatigue since control knobs are located at lower left side of instrument; vernier-type reading scale is at eye level. Two beam-arresting knobs are located at either side. Cantelever-type beam, with 10:1 ratio, is made of nonmagnetic aluminum alloy. Bearing surfaces are knife-edged, optically ground sapphire. Weighing times are claimed to average less than 18 sec. *E. Machlett & Son, 220 E. 23rd Street, New York 10, N. Y.* (P-28)

Moisture Meter

The Kappa electronic moisture meter operates at radio frequency on the capacity change principle. The unit

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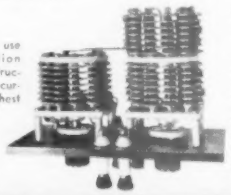
Resistance elements in these Megohm Decade Boxes are wound non-inductively on ceramic forms with a specially developed alloy wire having a negligible temperature coefficient over a range from —50° C to +80° C. Each spool's resistance, as well as that of the entire decade, is held within a deviation of 1/10 of 1% throughout this temperature range, and provides even greater stability at room temperatures. Accuracy is maintained over a frequency range from DC to 20 KC.

Each spool safely dissipates 2 watts. The switch arm consists of multiple leaves of phosphor bronze that are self cleaning by wiping action, and the entire switch is heavily silver plated. This construction thereby assures continued accuracy of measurements over long periods of constant use.

Winslow Megohm Decade Boxes are available in 1, 2 and 4 dial models covering resistance ranges to 111.1 megohms. *Write for catalog.*



Interior view showing use of ceramic insulation throughout. This construction insures minimum current leakage and highest accuracy.

Model 340, 2 dials, measures to 110 megohms in steps of 1 megohm. Heavy aluminum case and panel provide complete shielding for AC measurements. Ground post in panel. Can also be used as a potential divider.

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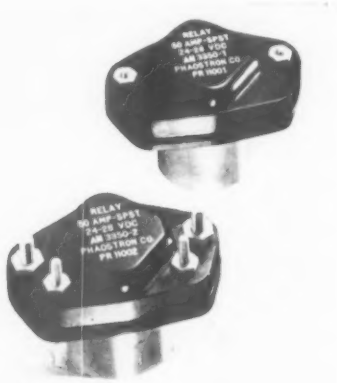
measures water content from 0.5% to 70%. The All-Purpose and S type meters provide two ranges of sensitivity; the S type has an expanded scale between zero and 15% moisture; the All-Purpose type permits discrimination better than 0.07%. *Marconi Instruments Ltd., Dept. NM, 23–25 Beaver St., New York 4, N. Y.* (P-29)

Voltage Indicator

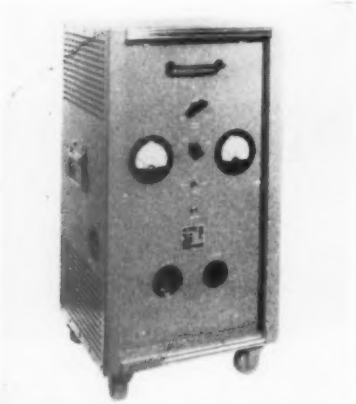
This high-low voltage indicator is for use with equipment whose efficiency is dependent on a certain voltage range. Model 961 indicates a low of 95–105 volts and a high of 130–140 volts. Model 960 indicates a low of 190–210 volts and a high of 235–255 volts. Both work on a-c or d-c. Units may be ordered for other ranges. *Industrial Devices, Inc., Edgewater, N. J.* (P-30)



50-Ampere Relay

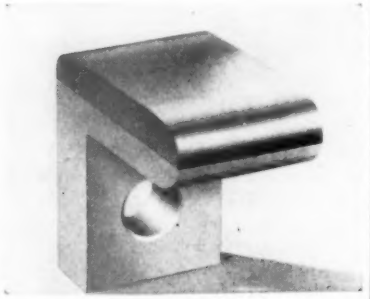
The PR-11000 series 50-ampere relay is a sealed single-pole single-throw relay. Basic application is as a magnet switch for remote control of currents up to 50 amperes at continuous duty. Nominal operating voltage is 24–28 volts. It is claimed to withstand temperatures of −55 to 70° C, shock at 26 G's, vibration of 10–55 cycles/sec at maximum excursion of 0.06 in. and 10 G's of continuous acceleration without malfunctioning.

Insulation between grounded parts and termination withstands potential of 100 rms for 60 sec. *Phaostron Co., 151 Pasadena Ave., South Pasadena, Calif.* (P-31)



Regulated D-C Supply

The model MA2850 tubeless regulated d-c supply, using magnetic amplifier principles, delivers 50 amperes at 23-32 volts. Regulation accuracy is ±1% against line and load combined. *Sorenson & Co., Inc., 375 Fairfield Ave., Stamford, Conn.* (P-32)



Copper-Graphite Contacts

The types UC-5 and UC-7 copper-graphite electrical contacts, made by powder metallurgy processes, are said to have higher conductivity and greater mechanical strength than those made by impregnating graphite with copper. Graphite imparts self-lubricating properties, reduces welding tendency, and does not tarnish. *Gibson Electric Co., Frankstown Ave., Pittsburgh 21, Pa.* (P-33)

Diffusion Pump Oil

This diffusion pump oil, Cencoil-B, for use in diffusion and fractionating pumps, is highly purified di-2-ethyl-

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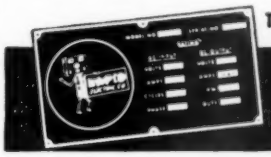

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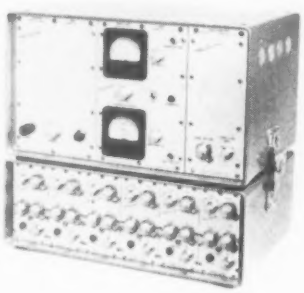

Amplifier System

The model 119 amplifier system provides a complete static and dynamic measuring system. It is contained in two sections, one containing the rectifier, regulator and oscillator units, and the other the six amplifier channel units. The system utilizes a stable 5,000-cps carrier frequency. Resulting oscillographic recordings have flat response from zero to 1,000 cps; less than 0.5 mv rms input signal is required for full-scale output. *Heiland Research Corp., 130 E. Fifth Ave., Denver, Colo.* (P-35)

Capacitors

The types 722-MD and 722-ME capacitors are calibrated in terms of capacitance difference rather than terminal capacitance; scales read directly capacitance removed from circuit. Each model has two sections, one having $\frac{1}{10}$ the range of the other. The 722-MD has capacitance-difference ranges of 0–1,050 and 0–105 $\mu\mu$f; 722-ME has ranges of 0–105 and 0–10.5 $\mu\mu$f. Plates and most other parts are aluminum. *General Radio Co., 275 Massachusetts Ave., Cambridge 39, Mass.* (P-36)

Impulse Magnetizer

The model 8100 magnetizer is designed to magnetize shapes that cannot be processed with an electromagnet. Input power requirement is 220–440 volts, 32–16 amperes (maximum), 60 cycles single phase. Control circuit stabilizes voltage to ±2% for line-voltage fluctuations of +10 to −20%. *Raytheon Mfg. Co., Equipment Sales Div., Waltham 54, Mass.* (P-37)

Erbium Oxide

This erbium oxide, of 98% minimum purity, has as its principal impurities fractional percentages of dysprosium, holmium, thulium, ytterbium, and yttrium oxides. Detailed analyses can be furnished with each lot. *Research Chemicals, Inc., Box 431, Burbank, Calif.* (P-38)

Time-Delay Generator

The model A-5 time-delay generator produces variable time delays from 1 to 1,000 μsec. Three ranges are pro-

vided, giving full-scale readings of 10, 100, and 1,000 μsec. Blocking oscillator output is provided. Incremental delays as small as 10 mμsec per division are available. *Rutherford Electronics Co., 3707 S. Robertson Blvd., Culver City, Calif.* (P-39)

Pulse Transformers

The SP-1 pulse transformer sample package, containing one each of types PT-1, PT-2, and PT-3, provides units for experimental circuits. They are all of the octal-base tube plug-in contruction with magnetic, wound, uncut cores. Respective characteristics are: inpedance—100, 100, 120 ohms; rise time—0.04, 0.04, 0.03 μsec; drop in 1 μsec is 20%. *Berkshire Laboratories, 538 Beaver Pond Rd., Lincoln, Mass.* (P-40)

Gas-Volume Meter

This pocket-size gas-volume meter continuously indicates volume within 5% in the flow rate range 5–65 liters per min. Principle is positive displacement; as gas is introduced, a set of rotors turn. Calibrated dial indicates cubic centimeters in the large dial and liters on the small dial. *J. J. Monaghan Co., Inc., 500 Alcott St., Denver, Colo.* (P-41)

INDUSTRY NOTES

▶**Fischer & Porter Co.,** Hatboro, Pa., by acquiring patents and engineering personnel of Electrical Development Co., Inc. and Digi-Coder Corp., is enabled to offer complete systems for plant and production automation.

▶**Tracerlab, Inc.,** 130 High St., Boston 10, Mass., and its subsidiary, Keleket

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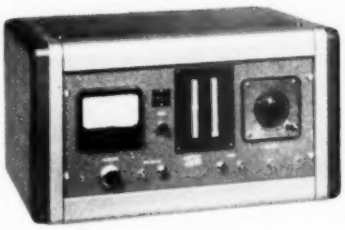

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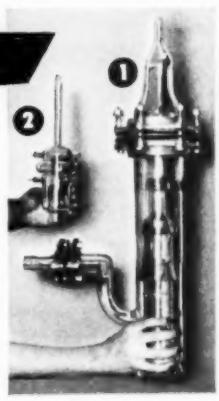

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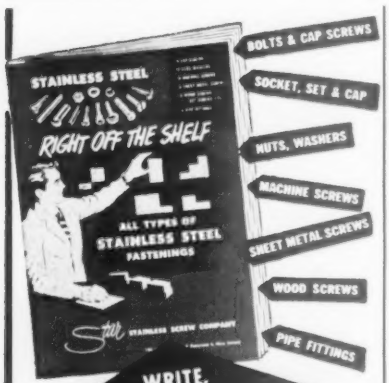

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X-Ray Corp., had a consolidated net income for 1953 of $143,282 after taxes. Sales were at a record high of $12,864,414.

▶**International Testing Service,** 321 N. Hamilton St., Saginaw, Mich., division of Jackson and Church Co., has created a theoretical physics department. It is headed by Dr. Robert L. Echols, one-time head theoretical physicist for Fairchild Aircraft's NEPA atomic project.

LITERATURE AVAILABLE

Du Pont's industrial medicine program. Focusing on the Haskell Laboratory for Toxicology and Industrial Medicine, "Protecting the Public Health" sets a precedent in employee and public relations that might be followed profitably by other companies, particularly in the nuclear field. This booklet describes studies made by the laboratory to assure that products may be safely introduced commercially and to answer problems of safety and health in the plant. *E. I. du Pont de Nemours and Co., Inc., Public Relations Dept., Wilmington 98, Del.* (L-1)

Pilot plant equipment. Bulletin 700 gives data on equipment including attrition mills, pumps, blending machines, autoclaves, and sterilizers. *Andrew Technical Service, 6972 N. Clark St., Chicago 26, Ill.* (L-2)

Oscillographic recording systems. Catalog describes systems and accessories for 4, 2 and 1 channel recorders. *Sanborn Co., Industrial Div., 195 Massachusetts Ave., Cambridge 39, Mass.* (L-3)

Circuit-closing device. Bulletin 71BS105 describes portable safe emergency closing device for use with standard air magnetic circuit breakers. *Allis-Chalmers Mfg. Co., 1316 S. 70th St., Milwaukee, Wis.* (L-4)

Electric stopwatches. Bulletin 646 describes timer providing increments of $\frac{1}{100}$ min or $\frac{1}{10}$ sec. *Precision Scientific Co., 3737 W. Cortland St., Chicago 47, Ill.* (L-5)

Beryllium-copper tubing. Memorandum 7-2 gives properties, applications, and advantages of seamless, welded tubing. *Superior Tube Co., 1552 Germantown Ave., Norristown, Pa.* (L-6)

Industrial refrigeration. Folder describes environmental test equipment to simulate low and high temperature, humidity, and altitude. *Murphy & Miller, Inc., 1326 S. Michigan Ave., Chicago 5, Ill.* (L-7)

Radiation survey instrument. Bulletin 486 describes model SM3 Geiger-Müller portable survey instrument. *El-Tronics, Inc., 2647-67 N. Howard St., Philadelphia 33, Pa.* (L-8)

Wire-wound resistors. Bulletin D-1 gives characteristics, applications, and construction of mil-type resistors. *International Resistance Co., 401 N. Broad St., Philadelphia 8, Pa.* (L-9)

Stationary vacuum systems. Bulletin A-939 describes line of equipment for combatting industrial dust. *U. S. Hoffman Machinery Corp., 105 Fourth Ave., New York, N. Y.* (L-10)

Electrode potential control. Bulletin 2210 describes apparatus for controlling potentials within 100 mv. *American Instrument Co., Inc., Silver Spring, Md.* (L-11)

Institute of Environmental Equipment Manufacturers. Brochure outlines Institute activities, membership classifications, contents of publications, and rules of Institute science contest. *Dr. George D. Wilkinson, General Manager, Institute of Environmental Equipment Manufacturers, 30 Church St., New York 7, N. Y.* (L-12)

Air-actuated controls. Bulletin 414-1 describes line of operators for converting air signals into mechanical motion, e.g., for valves and dampers. *Minneapolis-Honeywell Regulator Co., Industrial Div., Wayne and Windrim Aves., Philadelphia 44, Pa.* (L-13)

Recording oscillograph. Bulletin CEC-1500C describes type 5-114 for recording static or dynamic data. *Consolidated Engineering Corp., 300 N. Sierra Madre Villa, Pasadena 15, Calif.* (L-14)

Circuit-loading errors. Keithley Eng. Notes, Vol. 1, No. 2, discusses means to reduce circuit-loading errors introduced by measuring instruments. *Keithley Instruments, 3868 Carnegie Ave., Cleveland, Ohio.* (L-15)

Impact machines. Bulletin 4211 describes machines with maximum capacities of 240 and 48 ft-lb for metals and plastics. *Baldwin-Lima-Hamilton Corp., Philadelphia 42, Pa.* (L-16)

Tubular electric heaters. Bulletin 202 describes heater for such uses as viscous liquids in tanks and pipes, frozen water systems, and convection heating. *Turbine Equipment Co.,*

Hynes Electric Heating Div., Box 578, Westfield, N. J. (L-17)

Radiation instrumentation. Catalog describes instruments for use with radioactive materials. *Isotope Accessories Co., 5646 Cedar Ave., Philadelphia 43, Pa.* (L-18)

Solenoid direct-lift valve. Bulletin 100 gives specifications of 5,000-lb/in.^{2} stainless-steel valves for $\frac{1}{8}$- and $\frac{1}{4}$-in. pipes. *Atkomatic Valve Co., Dept. B228, 545 W. Abbott St., Indianapolis, Ind.* (L-19)

Research reactor catalog. "Nuclear Reactors for Science and Industry" lists research reactors North American is prepared to design and build for qualified scientific and industrial groups. The three basic types described are the solution, pool, and homogeneous graphite types. *North American Aviation, Inc., International Airport, Los Angeles 45, Calif.* (L-20)

Time-delay generator. Data sheet on model A-5 generator outlines possible uses of instrument. *Rutherford Electronics Co., 3707 S. Robertson Blvd., Culver City, Calif.* (L-21)

X-ray diffraction powder camera. Information sheet describes how five separate diffraction patterns on one film may be obtained with model HC-101 high-temperature camera. *Central Research Laboratories, Inc., Dept. KP, Red Wing, Minn.* (L-22)

R-F shielding. "Evaluating Shielded Enclosures" discusses advantages of shielding materials and how their effectiveness is measured. *Ace Engineering and Machine Co., 3644 N. Lawrence St., Philadelphia 40, Pa.* (L-23)

Radiation-measuring instruments. Form 3017-A contains specifications for medical X-ray control, personnel dosimeters, health survey and isotope laboratory instruments and accessories. *Victoreen Instrument Co., 5806 Hough Ave., Cleveland 3, Ohio.* (L-24)

High-vacuum equipment. Booklet describes pumps and accessories, gages, and equipment for coating and freeze drying. *W. Edwards & Co. (London) Ltd., Worsley Bridge Rd., London, S.E. 26, Eng.* (L-25)

Radiation devices. "Radiation Digest," published quarterly, presents articles and abstracts of current literature on industrial applications of x-rays and similar radiations. *General Electric Co., X-Ray Dept., 4855 Electric Ave., Milwaukee, Wis.* (L-26)

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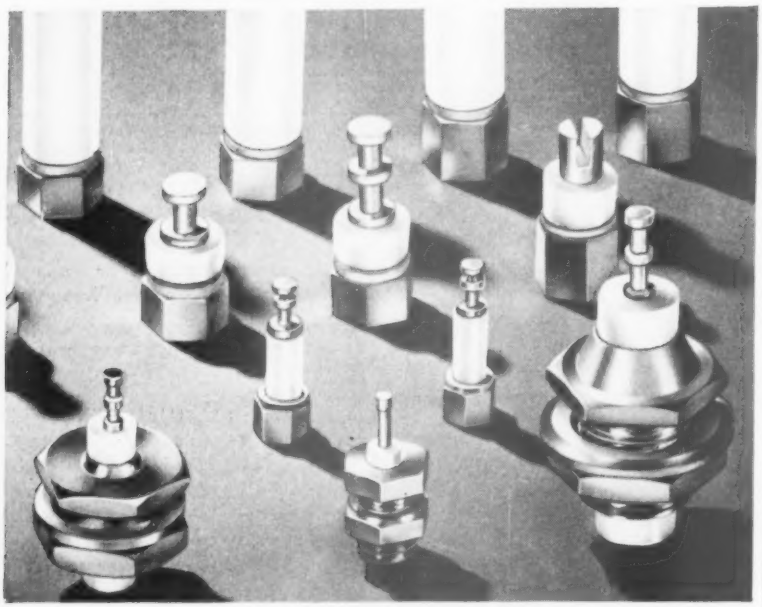

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Linearity: Within 1%, from 0 to 90 volts output			
Bandwidth:	Delay line (2.0MC)	9.5MC	0.1MC
Rise Time:	0.2usec	0.7usec.	5.0usec.
Decay Time:	0.8usec.	5.0usec.	25usec.
Maximum Gain: (High Level)	1,600	6,000	12,000

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electrical characteristics

INPUT IMPEDANCE
1500 ohms

CURRENT SENSITIVITY
0.6 x 10^{-9} amperes per millimeter

VOLTAGE SENSITIVITY
1 microvolt per millimeter

OPERATING VOLTAGE
115 volts, 60 cycles

● **REFERENCE DATA: Write for Instrumentation Data Sheet No. 10.0-12.**

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